HONDA

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April 5, 2004

Docket Management Facility, Room PL-401
National Highway Traffic Safety Administration
400 Seventh Street, S.W. Nassif Building
Washington, D.C. 20590

Subject: Docket No. NHTSA-03-15715
Request for comments;
49 CFR Part 571.208: Occupant Crash Protection

Dear Sir or Madam:

Enclosed are the comments of Honda Motor Co., Ltd. and American Honda Motor Co., Inc. regarding the above-referenced docket.

We thank you for this opportunity to provide our comments. If you have any questions, require additional data or require further clarification, please contact us at your earliest convenience.

Sincerely,

AMERICAN HONDA MOTOR CO., INC.

William R. Willen

William R. Willen
Managing Counsel
Product Regulatory Office

WRW: jj

Enclosures

Comments of Honda Motor Co., Ltd. and American Honda Motor Co., Inc. on 49 CFR Part 571 Docket No. NHTSA-03-15715

April 5, 2004

SUMMARY COMMENTS

Honda supports NHTSA's proposal to introduce the high-speed frontal Offset Deformable Barrier (ODB) crash test into the NCAP program as a means to improve "self-protection" (protection of the driver and occupants of the principle vehicle being tested). However, Honda strongly recommends that NHTSA should consider simultaneously introducing into the NCAP program a Full-width Deformable Barrier (FDB) crash test, using load cells to examine structural performance in order to judge a vehicle's "partner-protection" (protection of the driver and occupants of the vehicle colliding into the subject test vehicle).

Introducing both the ODB and FDB crash tests at the same time would serve to minimize any potential disbenefits in vehicle crash compatibility that may result from the ODB test by itself.

While Honda generally supports the introduction of these tests into the NCAP program, we do not believe that either test is mature enough and/or the fleet-wide effects understood well enough to include them in a regulation at this time.

DETAILED COMMENTS

Honda believes that enhancing the performance of frontal occupant crash protection is important in variable frontal collision configurations as a matter of self-protection.

Recently, the Insurance Institute for Highway Safety (IIHS) showed that a vehicle that earns a good rating in the IIHS ODB crash test shows a benefit in reduced fatality risk in the real world[1]. However, IIHS did not fully analyze differences in vehicle weight, driver age, vehicle age, and other factors.

On the other hand, NHTSA testing showed that the introduction of the high-speed offset test might increase the aggressivity of SUVs in vehicle-to-vehicle crashes[2].

Therefore, Honda believes that self-protection and partner-protection must be considered as important safety performance criteria at the same time and relative to each other. (See Attachment 1)

The introduction of a partner-protection evaluation has no potential disbenefit. Therefore, Honda suggests that NHTSA introduce a FDB test into NCAP with partner-protection criteria to assess compatibility at the same time as NHTSA's introduction of a high-speed ODB crash test into NCAP.

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[1] IIHS Status Report, Vol. 39, No. 2, February 7, 2004

[2] 69 FR 5111

Honda believes that a vehicle design can satisfy both self-protection and partner-protection performance. A forthcoming certain model is an example where Honda has achieved well-balanced performance between self-protection and partner-protection by employing our new Advanced Compatibility Engineering (ACE) front structure. The model has been redesigned to improve self-protection without increasing aggressivity in frontal crashes. (See Attachments 1-6)

Meanwhile, Honda has been studying how to use analytical techniques such as finite element modeling to evaluate vehicle partner-protection/aggressivity without carrying out an experimental evaluation[3]. The redesigned model has also been examined by experimental evaluation.

As a first step in evaluating partner-protection/aggressivity, Honda's recommendation is to use the Full-Width Deformable Barrier with load cells to measure the forces in rows 3 and 4 (shown as rows C and D on attached illustration)[125 mm X 125 mm load cells] to control frontal force levels and force distribution. This evaluation will help match the principle vehicle forces and stiffness at the specific interaction area where NHTSA and most other countries require that bumpers be located (See Attachments 4, 5).

Since there is little definitive research on the combined USA fleet-wide effects of the introduction of a high-speed ODB self-protection requirement in combination with a FDB partner-protection requirement, Honda does not believe either test is mature enough and/or the effects well understood enough to be introduced as a FMVSS at this time.

In order to develop the necessary and appropriate new criteria and assessment methods for both tests and to examine the vehicles that are developed as a result, the Agency should introduce them as NCAP tests and study the outcomes before using either of them in a regulation. The Thor-Lx leg assemblies could be used with the belted AM50% dummy to begin to assess lower extremity injuries with more accuracy and detail in both tests. Successful use of the Thor-Lx leg assemblies is also dependent on resolving the existing concerns over calibration procedures, repeatability and durability of the assemblies.

As a future second step, Honda recommends research to study replacing the load cell equipped FDB test with a load cell equipped Moving Deformable Barrier (MDB) test. The MDB test has the possibility to further enhance vehicle-to-vehicle crash performance by adjusting vehicle structural performance in relation to vehicle weight.

3 See Attachment 11: SAE paper 2004-01-1162

Honda Comments for NHTSA Questions:

1) *Are NHTSA's anticipated safety benefits associated from a fixed offset deformable barrier crash test requirement provided in Section IV realistic? Please provide data to support any views.*

We agree with NHTSA data that occupants involved in frontal offset crash experience hip and lower extremity injury. We do not have any additional analysis on the potential for reducing those injuries.

2) *In addition to potential disbenefits to the occupants of collision partners described in this notice, are there other potential disbenefits NHTSA should consider? Please provide data to support any views.*

In a 1998 study, Honda predicted an increased stiffness trend potential, based on vehicle weight, if a high-speed offset crash test were added into the frontal crash tests.[4]

Since that time Honda has been taking into consideration that a vehicle body structure should be designed to diminish aggressivity when a vehicle has a complete redesign.[5]

However, Honda did not study other potential disbenefits. Honda encourages the NHTSA to conduct such research and analysis if an ODB test is undertaken as a part of the NCAP program.

3) *Is it necessary to stiffen the front corners of vehicles to do well in a fixed offset deformable barrier crash test? Please explain the answer. Also, is the answer to this question different for different vehicle classes? If so, please explain the answer for each vehicle class.*

Honda believes it is not necessary to increase the stiffness of the vehicle front corners to perform well in an ODB test. It is important to maximize the energy absorbed in the engine compartment and to re-enforce the cabin strength. At the same time, the restraint system (airbag & seatbelt) needs to be optimized to maximize self-protection.

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4 See Attachment 12: ESV paper 1998-S1-O-08: "The offset crash test - A comparative analysis of test methods"

5 See Attachment 13: ESV paper 2003, Paper number 239-O: "Innovative body structure for the self-protection of a small car in a frontal vehicle-to-vehicle crash"

4) *If stiffening the front corners of vehicles to do well in a fixed offset deformable barrier crash test is just one alternative for improving performance, what other types of countermeasures are available to achieve good performance in a fixed offset deformable barrier crash test? What are the costs and required lead-time associated with these countermeasures?*

As mentioned in Q.3 we do not believe it is necessary to increase the stiffness of the front corners. Concepts such as our Advanced Compatibility Engineering (ACE) structure (See 2003 ESV Paper referenced in Q.2, above) can improve frontal crash performance without stiffening the front corners.

In a complete vehicle redesign, such structural improvements can be made efficiently with minimal cost increases. The lead-time needed depends on the complete redesign cycle of each model vehicle (i.e., “Full Model Change”).

5) *What are the constraints vehicle manufacturers must face in designing a vehicle to meet a high speed fixed offset deformable barrier crash test requirement? Which are the most difficult to overcome? What types of vehicles have the most constraints?*

A vehicle manufacture must make a balance between all frontal crash modes. Additionally, restraint system performance for all sizes of occupants, including out-of-position occupants, and the issue of partner-protection needs to be considered.

6) *Is it necessary for the agency to consider alternative strategies to prevent vehicles from being too stiff or aggressively designed as a result of a fixed offset deformable barrier crash test requirement?*

Of course it is the agency’s responsibility to consider the global fleet-wide effect of any new NCAP test or new regulation. Honda suggests that the agency simultaneously consider how to judge a vehicle’s aggressivity/compatibility to reduce this potential disbenefit. Honda recommends adding a load cell FDB test to facilitate such judgements in the near term and study a load cell MDB test for the long term.

7) *Are there certain vehicle classes or vehicle weights that should be exempted from a frontal offset crash test requirement? If so, please state the rationale for each vehicle class exemption or vehicle weight limitation.*

We have no suggestions on this issue for the near term. For the long term, the MDB test has some ability to allow compensation for vehicle weight.

8) *This notice discussed one potential alternative strategy establishing an additional performance requirement to limit stiffness and/or energy management. Is this an appropriate strategy to pursue? If so, what requirement should be established?*

As a first step, Honda recommends expanding the NCAP test program to use the Full Width Deformable Barrier with load cells to measure the forces in rows 3 and 4 [125 mm X 125 mm load cells] to control frontal force levels and force distribution. (see attachments 4 & 5)

As a second step the agency should consider replacing the Offset Deformable Barrier test and Frontal Fixed Deformable Barrier tests with a Moving Deformable Barrier test.

9) *Are there other alternative strategies, beyond those mentioned in this notice, which the agency should consider in conjunction with a fixed offset deformable barrier crash test requirement?*

Instead of the current Phase II of the advanced airbag rule - Honda suggests using the AF5% and AM50% dummies and replacing the current FMVSS 208 Full Width Rigid Barrier test at 56 km/h with a load cell equipped Full Width Deformable Barrier test at 56 km/h. Then, as is currently done, NHTSA can use FMVSS 208 to set regulatory values for head, neck, chest G, chest deformation and femur load. For the NCAP program, NHTSA can continue to calculate the combined head and chest injury probability and issue a star rating using this same 56 km/h FDB test.

Further, the 56 km/h FDB test would allow NHTSA to begin an assessment of partner-protection. In addition to the 56 km/h FDB 208/NCAP test for self-protection and partner-protection, NHTSA can add a 64 km/h ODB test as an NCAP -only test for self-protection. The Thor -Lx can be used to better assess lower extremity injury in all tests. However, current Thor -Lx has some problems to use for actual assessment test, for example, calibration procedure, repeatability, and durability, Honda thinks. Therefore, NHTSA should introduce Thor-La as NCAP tests after resolving the current concerns.

10) *What optimum test speed should be employed in the fixed offset deformable barrier test so as to maximize occupant compartment integrity and at the same time ensure no undue stiffening of the fronts of large vehicles? What are the trade-offs between test speed and front-end stiffness of vehicles? Are the countermeasures dependent upon the test speed? If so, please explain the dependence.*

Honda suggests an offset deformable barrier test velocity of 64 km/h to ensure self-protection. This should give an equivalent crash severity of at least 56 km/h in a vehicle-to-vehicle test in a mid-size vehicle[6]. As discussed above, Honda recommends the simultaneous introduction of a load cell FDB at 56 km/h to control front-end force/stiffness.

[6] ESV paper 98-S1-O-08: "The offset crash test. A comparative analysis of test methods"

Honda comments on RFC of Federal Motor Vehicle Safety Standard; Occupant Crash Protection

Docket No. NHTSA-2003-15715
-Reference Material-

Confidential version

Note: This reference material includes ***confidential*** matters

Test Matrix and Results summary

Test Condition	"current" (99MY Vehicle A)	"redesign" (05MY Vehicle A)	*Attachment No.*
Self protection **F**ull- lap **R**igid **B**arrie **35mph**	**NCAP rating :** **5? Drive** **5? FR. Passenger**	***Maintained performance***	2
High-speed **O**ffset **D**eformable **B**arrier **40mph**	**IIHS Rating : Good**	***Improved performance***	3
Partner and Self protection **F**ull-width **D**eformable **B**arrier with Load Cell **35mph**	→	***Improved*** •***Reduced peak force*** •***Improved Homogeneity***	4-6
Vehicle-to-Vehicle test Struck vehicle B **31mph(50kmh)**	→	***No increase in Aggressivity***	7-9
Honda recommendation : Self protection and Partner protection Assessment Method and Criteria			10

Assessment Method and Criteria

Attachment No. 1

Compatibility

- **Partner-protection** (Aggressivity)
  - Test Method
    - Type of Barrier
    - Test Configuration
  - Evaluation Items
    - Barrier Force
    - Barrier Energy
    - Geometry
    - Stiffness
- **Self-protection**
  - Test Method
    - Type of Barrier
    - Test Configuration
  - Evaluation Items
    - Body Deformation
    - Body Deceleration
    - Injury Criteria
    - Rescue Risk

Self-protection : NCAP

Attachment No. 2

'99Vehicle-A(NHTSA test)

'05Vehicle-A(Internal)

[redacted]

Crash Test information

'99Vehicle-A :Tested by NHTSA

Frontal	HIC	Chest Deceleration(G's)	Femur Load (N)		
Driver's Side	320 HIC	41g	998	1326	★★★★★
Passenger's Side	358 HIC	37g	1163	1659	★★★★★

'05Vehicle-A : Tested by Honda(Internal)

Frontal	HIC	Chest Deceleration(G's)	Femur Load (N)
Driver's Side	[redacted]		
Passenger's Side			

Self-protection : ODB 40mph Test *Attachment No .3*

'99Vehicle-A(IIHS Test)

'05Vehicle-A(Internal)

[redacted]

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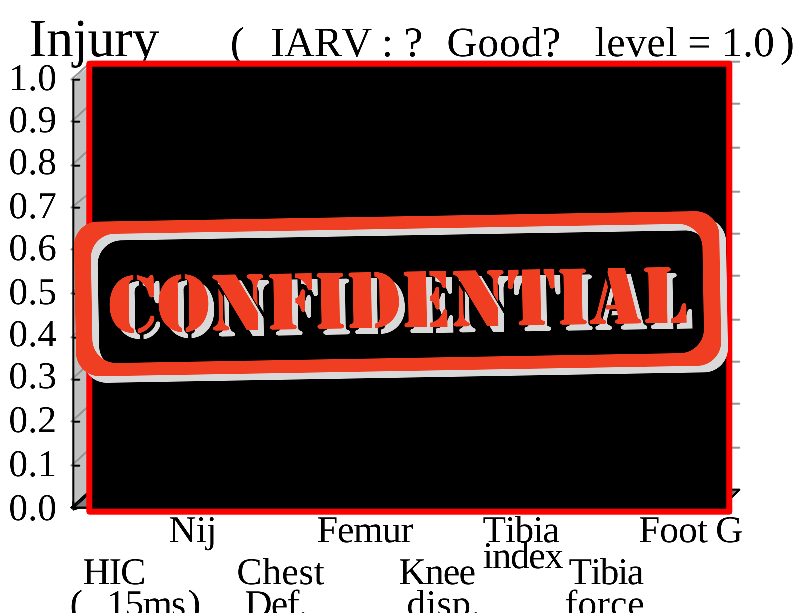
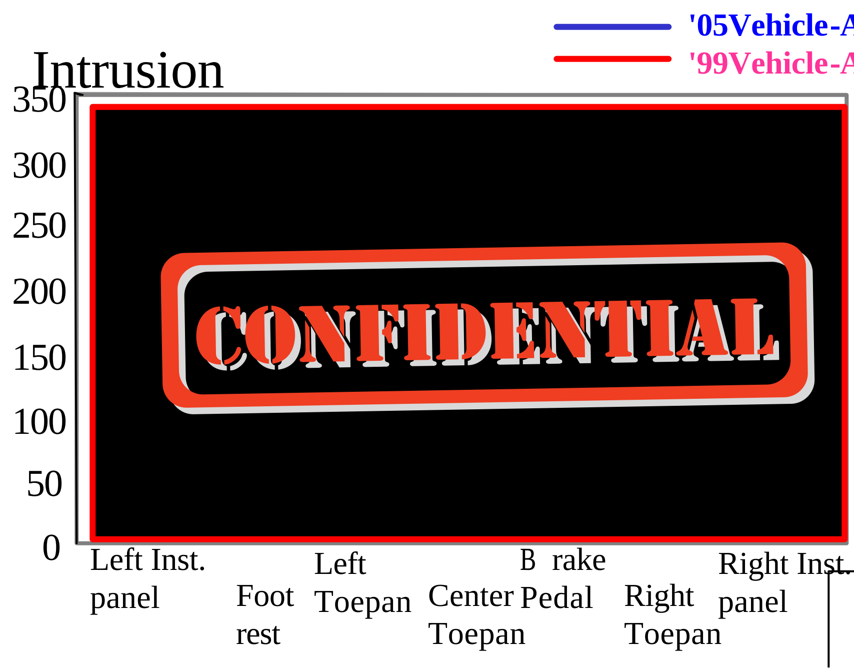
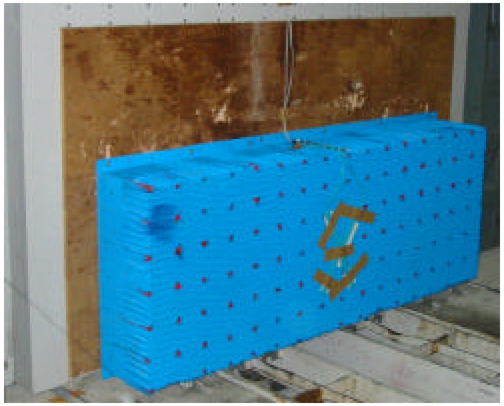


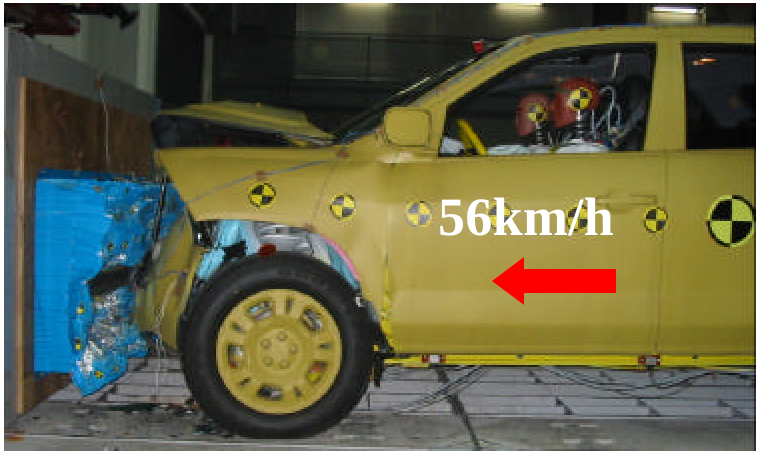


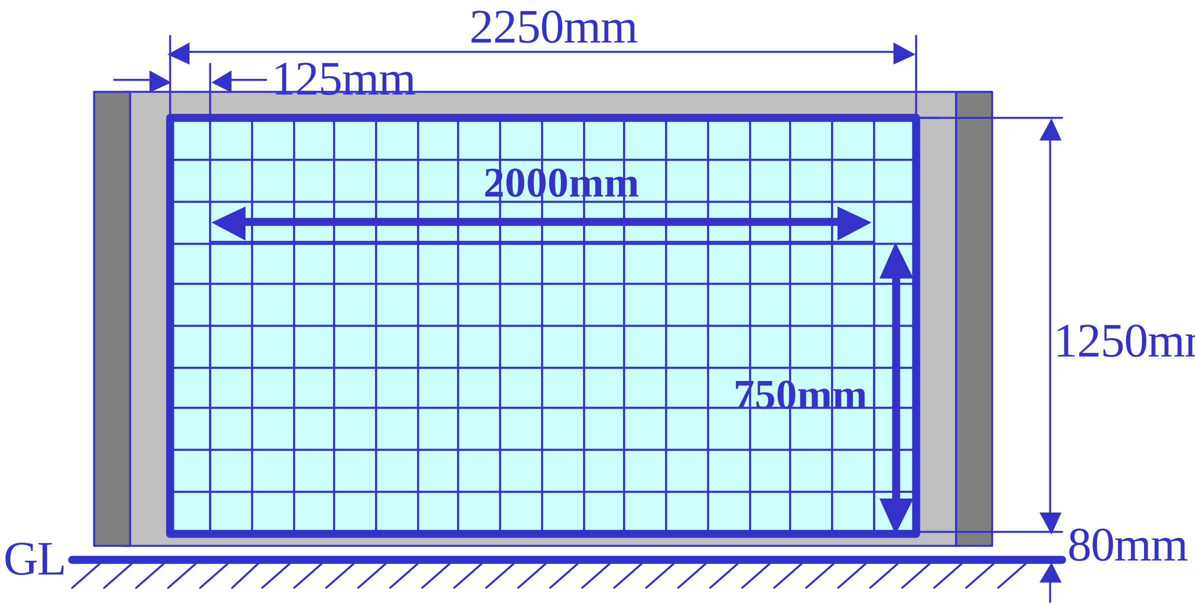
Partner-protection : FDB Test

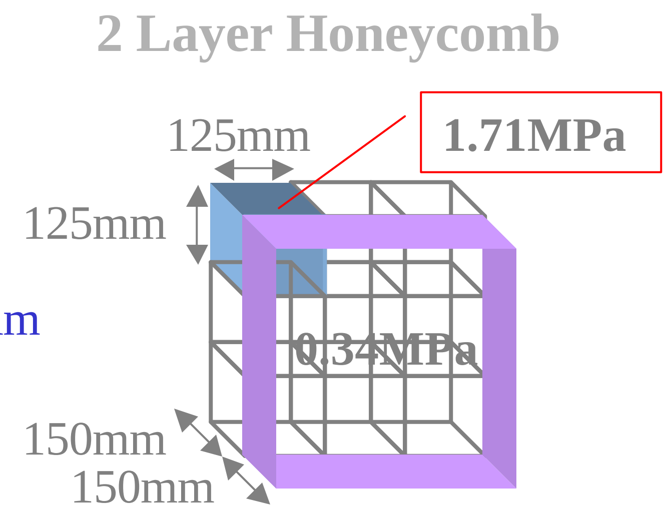
Attachment No. 4

Full-width Deformable Barrier Test 35mph









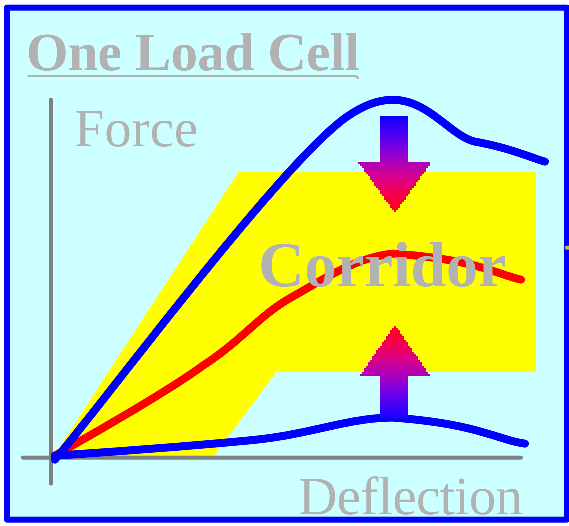
Data source : SAE 2004-01-1162

Partner-protection : FDB Test

Attachment No. 5

Assessment Criteria

Full -width Deformable Barrier Test 35mph



Limit Maximum Force
? Stiffness Matching

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Limit Minimum Force
? Override Prevention

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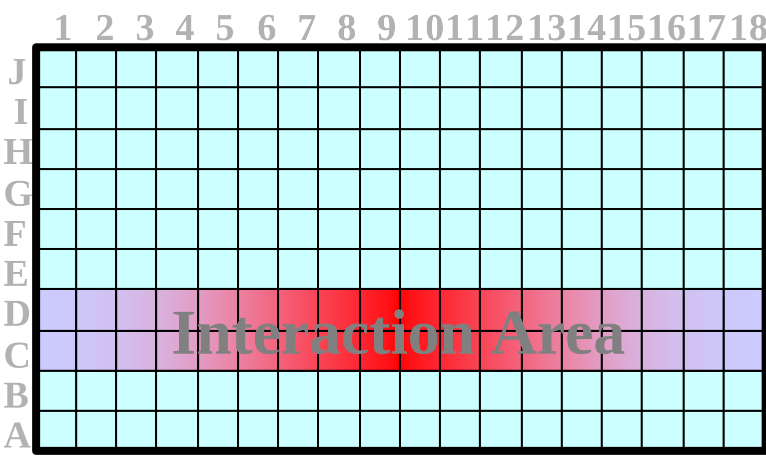

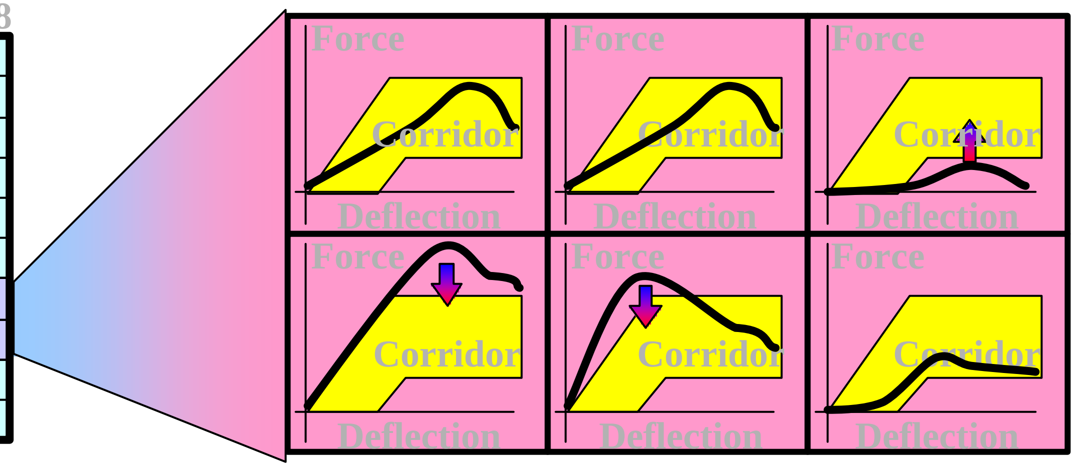

Data source : SAE 2004-01-1162

Partner-protection : FDB Test

Attachment No. 6

•Comparison of force at interaction area

Full-width Deformable Barrier Test 35mph

[redacted]

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•Comparison of Peak force and force distribution

'99V[redacted]

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'05V[redacted]

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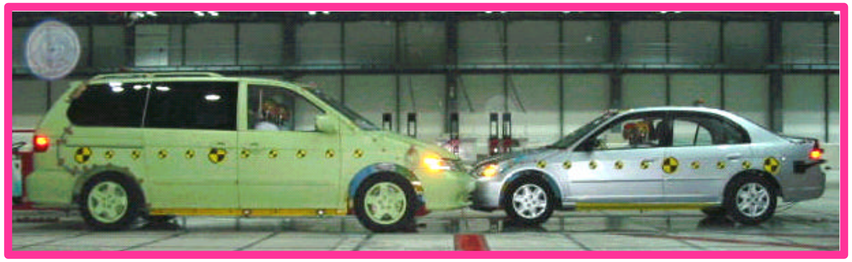
Vehicle-to-Vehicle Test

Attachment No. 7

'99Vehicle-A vs Vehicle-B



¦ Test mode　: Vehicle-B vs ‘99Vehicle-A
¦ Test Weight : Vehicle-B (1346.2kg)
‘99Vehicle-A (2206kg)
¦ Clash degree : Vehicle-B 50% LAP
¦ Clash speed : 31mph(50.0km/h)

'05Vehicle-A vs Vehicle-B

¦ Test mode　: Vehicle-B vs '05Vehicle-A
¦ Test Weight : Vehicle-B (1348kg)
'05Vehicle-A (2249kg)
¦ Clash degree : Vehicle-B 50% LAP
¦ Clash speed : 31mph(50.0km/h)

Vehicle-B

Vehicle-B

Vehicle-to-Vehicle Test

Attachment No. 8

Vehicle-B(Compact-Sedan)

	`99Vehicle-A vs	`05Vehicle-A vs
Test Weight	1346	1348
Mass Ratio	1: 1.64	1:1.67
Test Speed ? km/h?	50.6 : 50.3	50.2 : 50.1

Injury Criteria		Standard	Driv	Pass	Driv	Pass
Dummy Type(HY-?)		FMVSS 208	AM50%	AM50%	AM50%	AM50%
HIC		700(15m[redacted]				
Nij (TF)		1.0	[redacted]			
(TE)		1.0	[redacted]			
(CF)		1.0	[redacted]			
(CE)		1.0	[redacted]			
CHEST G(3ms)	G	60G(3m[redacted]				
Chest Deflection	mm	63mm	[redacted]			
Femur R	N	10000N	[redacted]			
Femur L	N	10000N	[redacted]			
Tibia Index R/Upper		1.3	[redacted]			
Tibia Index R/Lower		1.3	[redacted]			
Tibia Index L/Upper		1.3	[redacted]			
Tibia Index L/Lower		1.3	[redacted]			

Body Deformation	[redacted]
A Piller Intrusion	[redacted]
Toe Board Intrusion/Upper	[redacted]
Toe Board Intrusion/Lower	[redacted]
Steering Wheel Movement/Upward	[redacted]
Steering Wheel Movement/Rearward	[redacted]

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Vehicle-to-Vehicle Test

Attachment No. 9

Vehicle-A(Minivan)

	Vehicle-B vs	Vehicle-B vs
Test Weight	2206	2249
Mass Ratio	1: 1.64	1:1.67
Test Speed ? km/h?	50.6 : 50.3	50.2 : 50.1

Injury Criteria		Standard	Driv	Pass	Driv	Pass
Dummy Type(HY-?)		FMVSS 208	AM50%	AM50%	AM50%	AM50%
HIC		700(15m [redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Nij (TF)		1.0	[redacted]	[redacted]	[redacted]	[redacted]
(TE)		1.0	[redacted]	[redacted]	[redacted]	[redacted]
(CF)		1.0	[redacted]	[redacted]	[redacted]	[redacted]
(CE)		1.0	[redacted]	[redacted]	[redacted]	[redacted]
CHEST G (3ms)	G	60G(3ms [redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Chest Deflection	mm	63mm	[redacted]	[redacted]	[redacted]	[redacted]
Femur R	N	10000N	[redacted]	[redacted]	[redacted]	[redacted]
Femur L	N	10000N	[redacted]	[redacted]	[redacted]	[redacted]
Tibia Index R/Upper		1.3	[redacted]	[redacted]	[redacted]	[redacted]
Tibia Index R/Lower		1.3	[redacted]	[redacted]	[redacted]	[redacted]
Tibia Index L/Upper		1.3	[redacted]	[redacted]	[redacted]	[redacted]
Tibia Index L/Lower		1.3	[redacted]	[redacted]	[redacted]	[redacted]

Body Deformation	[redacted]
A Piller Intrusion	[redacted]
Toe Board Intrusion/Upper	[redacted]
Toe Board Intrusion/Lower	[redacted]
Steering Wheel Movement/Upward	[redacted]
Steering Wheel Movement/Rearward	[redacted]

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Honda Recommendation

<u>Short term</u>

Self Protection:

1- As FRB FMVSS 208 will be at the same speed as current FRB NCAP, current FRB NCAP is no longer needed.

2- ODB test at 40 mph can be added to NCAP

Self & Partner protection:

3- NCAP should be replaced with FDB test, at current NCAP speed, to measure agressivity and compatibility and self protection performances.

<u>Long Term</u>

Self & Partner protection:

4- MDB test is for the future.

FRB: **F**ull- lap **R**igid **B**arrier

ODB: **O**ffset **D**eformable **B**arrier

FDB: **F**ull-width **D**eformable **B**arrier

MDB: **M**oving **D**eformable **B**arrier

2004-01-1162

Experimental Evaluation of Test Procedures for Frontal Collision Compatibility

Satoshi Takizawa, Eisei Higuchi, Tatsuo Iwabe, and Tomiji Sugimoto
Honda R&D Co., Ltd.

Takayuki Kisai, Takayuki Suzuki
PSG Co., Ltd.

ABSTRACT

This paper investigates test procedures for vehicle frontal crash compatibility. Both Full Width Deformable Barrier (FWDB) tests and Moving Deformable Barrier (MDB) tests were studied to assess relevant factors of compatibility issues.

The FWDB test with load cells was examined to evaluate the stiffness and interaction areas of vehicles (sometimes referred to as the “aggressivity” of vehicles). Compatibility metrics were computed using barrier load cell data and the output from the FWDB test was compared with that from the Full Width Rigid Barrier (FWRB) test. Since the results obtained from these two full width tests were considerably different, a full frontal vehicle-to-vehicle test was carried out to identify structural deformation modes. The results indicated that similar deformation modes were observed between the vehicle-to-vehicle test and the FWDB test.

MDB-to-vehicle tests were conducted to replicate vehicle-to-vehicle tests and to evaluate relevant self-protection characteristics of a small vehicle. The deformable face for the MDB that was developed by the load cell wall data in the FWDB test reasonably reproduced the crash characteristics of the actual vehicle.

INTRODUCTION

Various laboratory crash test procedures are being studied to evaluate crash compatibility performance of vehicles. Compatibility performance is determined both by self-protection performance and aggressivity; therefore compatibility assessment must have test methods and performance criteria for these two requirements. This paper will discuss a research program for developing a set of compatibility test procedures to assess both self-protection and aggressivity.

In order to improve compatibility, it is necessary to evaluate and control relevant vehicle characteristics of compatibility in test procedures. According to the International Harmonized Research Activity (IHRA) study, relevant aspects for compatibility in a frontal impact are [1]

- Good structural interaction
- Frontal stiffness matching
- Occupant compartment strength
- Control of the deceleration time histories of impacting vehicles

These four considerations may be applied to each impact stage during a frontal impact. Namely, good structural interaction is applied to the early stage of the impact. Frontal stiffness matching applies from the early stage to the final stage. Occupant compartment strength is a factor in the final stage. Controlling the deceleration time histories of impacting vehicles is a goal for the entire duration of the impact. Candidate test procedures should be chosen to evaluate performance relative to the goals at each impact stage.

Barrier load cell data in the US New Car Assessment Program (US-NCAP) was investigated by the National Highway Traffic Safety Administration (NHTSA). Some compatibility metrics such as the AHOF, initial force and force distribution were measured on the load cell wall (LCW) [2][3]. Those metrics may control structural interaction and frontal stiffness and that would be beneficial to enhance the interaction characteristics of vehicles. Therefore, a full width barrier test with a load cell wall could be a candidate test procedure to evaluate the interaction characteristics. However, it is said that when vehicles crash into a rigid wall, an unrealistic barrier load is measured on the load cell wall due to the contact between the large mechanical parts and the rigid wall. In order to reduce inertial forces of the mechanical parts acting on the LCW, Transport Research Laboratory (TRL) developed a full width deformable barrier (FWDB) test [4][5]. The work described in this paper provides a comparative analysis between the FWDB test and the full width rigid barrier (FWRB) test.

An MDB test can produce relatively realistic vehicle-to-vehicle crash response, deformation and occupant kinematics. Typically, when small vehicles are crashed into large vehicles, small vehicles experience harsher damage. Therefore, passenger compartment space and deceleration time histories are most significant for small vehicles to enhance their self-protection performance. In our previous study, nothing reproduced the deceleration pulses generating in the vehicle-to-vehicle impact better than the MDB test [6]. As a consequence, the MDB-to-vehicle test could be a candidate to assess the passenger compartment strength and the deceleration pulse.

RELEVANT CHARACTERISTICS IN FRONTAL COMPATIBILITY

The present study was motivated by the two vehicle-to-vehicle tests from the previous study. The target vehicle was a compact four-door sedan representing a small passenger car in the US fleet. An SUV and LTV with different mass and geometry were selected for striking vehicles. SUV/LTV-to-car crash tests were performed with these cars impacted at 50 km/h each. The offset ratio for this test was 50% of the width of the compact sedan.

In these vehicle-to-vehicle tests, obvious overriding was seen in the LTV-to-car impact due to the difference in their relative heights. No overriding was seen in the SUV-to-car impact. The deformation modes of the target vehicle are shown in figures 1a and b. There was more intrusion in the LTV-to-car impact than in the SUV-to-car impact. Therefore, the vertical engagement of the front-end structures should be considered as a geometrical compatibility metric.

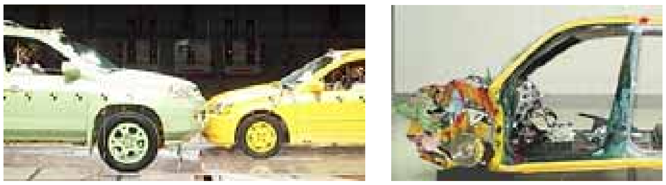

Figure 1a. SUV-to-Car Impact.

Figure 1b. LTV-to-Car Impact.

GEOMETRICAL COMPATIBILITY

As mentioned above, less structural interaction between the leading edges of vehicles can lead to override. Therefore, more structural interaction can lead to less override.

An FWRB test at 56 km/h with a load cell wall (US-NCAP) is one of the test methods to assess and control structural interaction. By evaluating force distribution measured on the load cell wall, one can identify and address areas where geometry can be changed for enhanced interaction. Figure 2 shows the configuration of the load cell wall, which consists of 180 load cells arranged in 18 by 10 matrix with each load cell size of 125 mm by 125 mm.

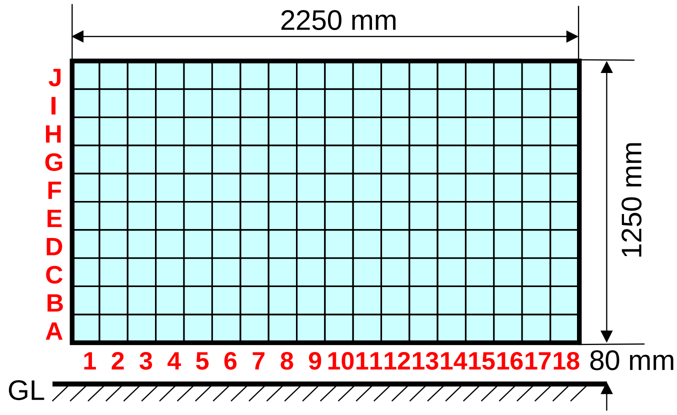

Figure 2. 180 Load Cells Barrier Configuration.

The Height Of Force (HOF) at each crush depth is computed from balancing the moments acting on each load cell with the total moment acting on the barrier. HOF's representatives of the LTV were compared with those of the SUV in an effort to better understand the overriding phenomenon. Figure 3 shows a plot of displacement versus HOF. The HOF's for the SUV and the LTV were generally higher than for the passenger cars. However, the HOF's were not constant throughout the crash. The HOF's for the LTV were near to or slightly lower than those were for the SUV up to 600 mm of the displacement. Thus HOF alone could not account for the overriding of the LTV.

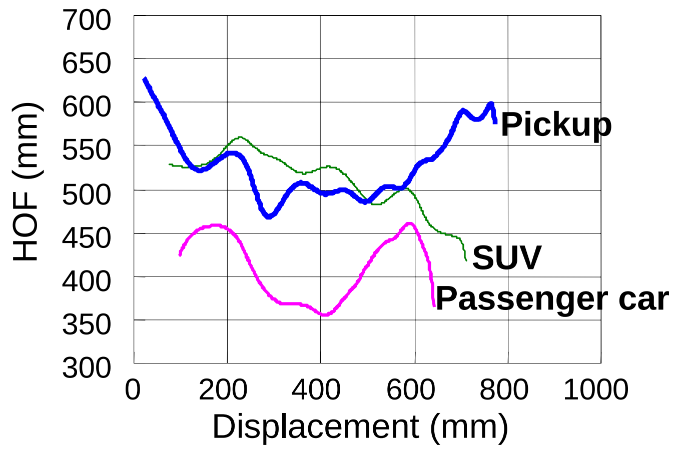

Figure 3. HOF-Displacement Curve

One of the reasons appears to be that the average height value does not consider force distribution. Figure 4 shows that vehicles with similar HOF value can have very different force distributions. In the SUV-to-car impact, the sub-frame of the SUV engaged the front structure of the passenger car and prevented override. Thus, force distribution plays an important roll to help prevent overriding. A wider interaction area should present less chance of override than a narrower interaction area. Therefore, compatibility metrics should consider the force distribution as well as the height of the center of the force.

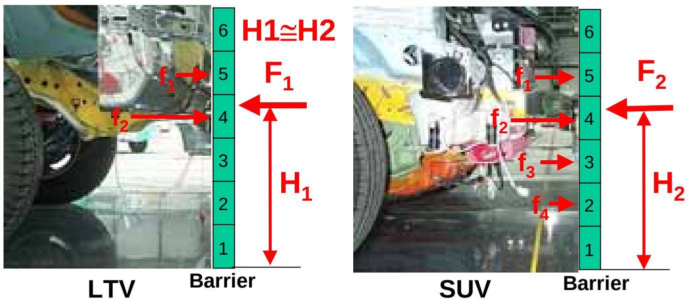

Figure 4. HOF and Force Distribution

Figure 5 shows the force distributions of various vehicles in an FWRB test. The most significant crash forces experienced by the passenger cars was at rows C and D (330 mm – 580 mm in height) because the front longitudinal members of the cars are around 457 mm (18 inches) in height because of the US bumper regulations. This area of force concentration may provide an opportunity to alter crash interaction.

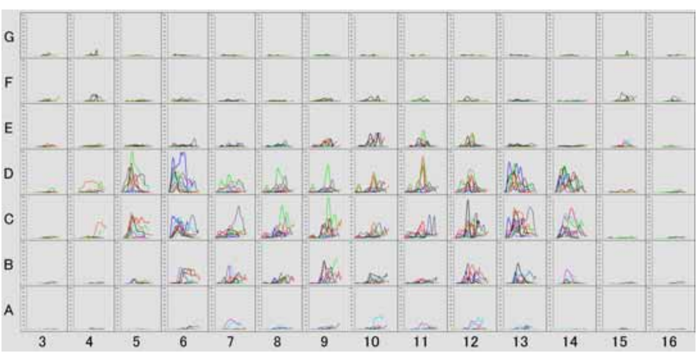

Figure 5. Force-Displacement Curve of Various Vehicles in the FWRB Test

STIFFNESS COMPATIBILITY

Once the interaction area is defined, interaction forces can be determined. Controlling force-displacement characteristics within the interaction area should enhance geometric compatibility and stiffness compatibility. In an ideal world, vehicle front-end structures would be identical. In the real world, management of force-displacement curves is one way of managing crash energy. Figure 6 demonstrates graphically how this concept might be brought to practice.

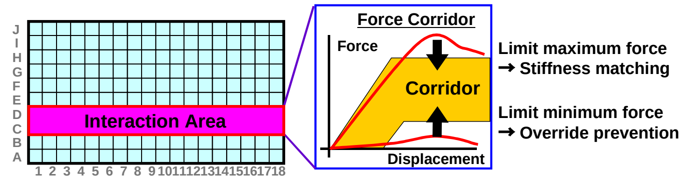

Figure 6. Interaction Area and Interaction Force

While some interaction forces can be determined in an FWRB test, vehicles interact differently with rigid walls than they interact with other vehicles. Large mass components can yield large inertial forces against rigid barriers. Such forces are not present in vehicle-to-vehicle impacts because the vehicle front is much softer than the rigid wall. For example, when an engine hits the rigid wall, very high inertial forces are generated and these forces have a great influence on the interactions of other components. Large inertial forces would also affect the proposed compatibility metrics such as HOF, initial stiffness, and homogeneity assessment. Since more realistic crash forces should determine the interaction forces, load cell data in the FWRB test was compared to those in the FWDB test.

FULL WIDTH DEFORMABLE BARRIER TEST

In order to control the inertial forces of mechanical parts, a deformable barrier face was fitted to the front of the load cell wall. Figure 7 shows the configuration of the FWDB. Currently the deformable barrier face that is proposed by TRL has two layers. The first layer consists of a 0.34 MPa honeycomb element with 150 mm deep, and the second layer consists of a 1.71 MPa honeycomb element with 150 mm deep. The second layer is segmented into individual blocks and is constructed so that each block is in line with each barrier load cell.

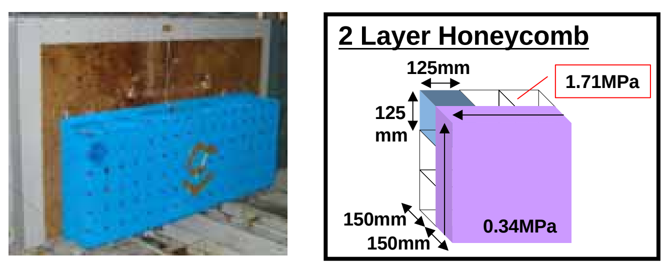

Figure 7. Two Layer Deformable Barrier Face and LCW

The load cell data in the FWDB test was compared with that in the FWRB test and the Force-Displacement (F-D) curve on the LCW for the SUV is displayed in Figure 8. The evidence that the deformable face filters the inertial forces derived from mechanical parts can be seen in the test results.

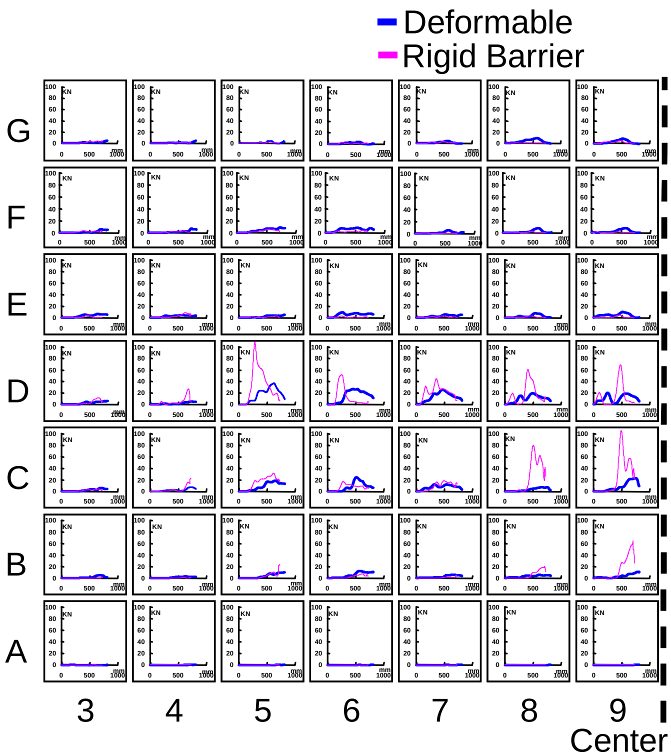

Figure 8. Force-Displacement Curve for the SUV

Having clarified the filter effect of the deformable face, FWDB tests were conducted with different categories of vehicles. These confirmed the variation between FWRB and FWDB results. Edwards, et al., proposed two assessment measures to evaluate the homogeneity of the vehicle front in the FWDB test. Firstly, the coefficient of variance (CV) was computed by CV = Standard Deviation / mean [4] and secondly, revised Homogeneity Assessment was measured [5]. The revised homogeneity criterion is based on the difference between peak cell load and target load level over a specified assessment area.

Total barrier force, the HOF, and the CV are compared in Figure 9. It was found from the result that the CV was much more sensitive to changes in F-D data than HOF.

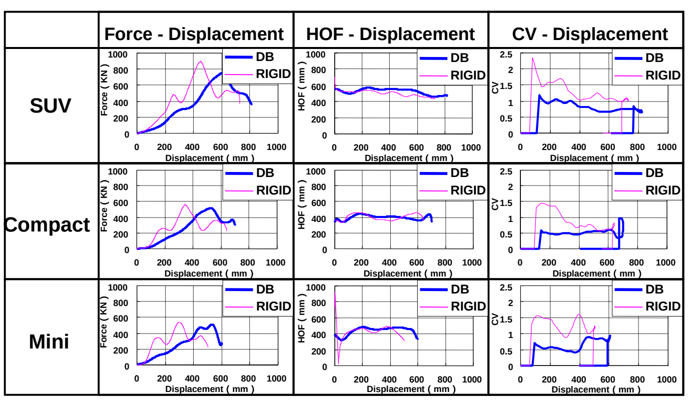

Figure 9. Force-Displacement Curve, HOF-Displacement Curve and CV-Displacement Curve

We then analyzed the revised homogeneity assessment and those were compared with the CV. The CV was computed over the entire time duration of the impact and was averaged by the crush displacement. The homogeneity assessment demonstrated similar trends to the CV among tested vehicles both in the FWDB and in the FWRB, see Figure 10. So far, the judgment of which homogeneity assessment criterion is better than another is open to discussion.

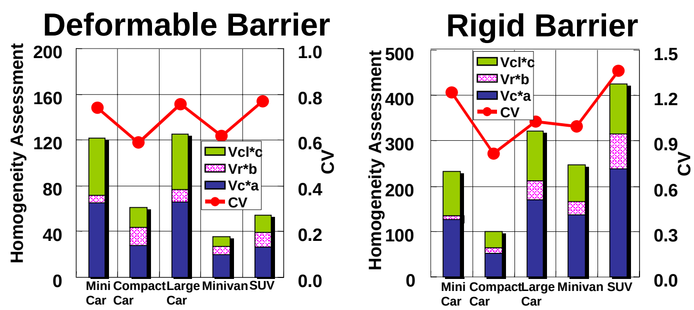

Figure 10. Comparison of the CV and Homogeneity Assessment

Homogeneity assessments differed depending on whether the test barrier was rigid or deformable. See Figure 11. Furthermore, the characteristics of the deformable face (strength and depth) can also change the homogeneity assessment. Care must be taken in establishing test procedures so those tests do not yield unrealistic results that would not aid in the effort to enhance compatibility.

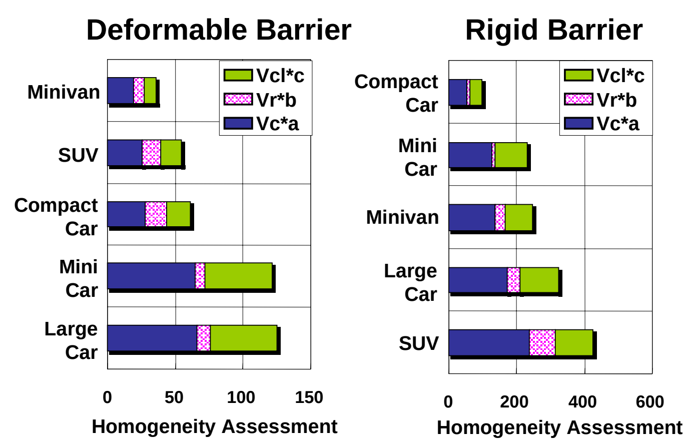

Figure 11. Comparison of the Homogeneity Assessment Measures

The typical deformation mode of the longitudinal member in the FWDB test was compared with that in the FWRB test. They are shown in Figure 12. The front-ends of the longitudinal members of the mini car were crumpled by impact with the rigid barrier. However, they penetrated into the FWDB's deformable face and there was less deformation of the same members. It was decided to investigate these differences further through vehicle-to-vehicle testing.

FWRB **FWDB**

Figure 12. Deformation Mode of the Longitudinal Member

VEHICLE-TO-VEHICLE IMPACT

Since the load cell data in the FWRB test was considerably different from that in the FWDB, vehicle-to-vehicle testing was conducted to identify which load cell data is more representative of the actual vehicle crush manner.

Two identical vehicles, of the same type discussed in the preceding section were selected and aligned for a front-to-front crash. See Figure 13.

Figure 13. Pre-Test Longitudinal Members

Figure 14 displays the deformation modes of the longitudinal members. As expected, the deformation mode of the longitudinal member in the vehicle-to-vehicle test was most similar to that in the FWDB test. Therefore the FWDB is preferable to the FWRB for assessing crash interactions of vehicles.

Vehicle-to-Vehicle **FWDB**

Figure 14. Post-Test Longitudinal Members

While the deformation mode of the longitudinal member was reasonably replicated in the FWDB test, the deceleration pulse in the early stages of the impact was much lower than that in the vehicle-to-vehicle. See Figure 15. The stiffness and the depth of the honeycomb element control the deceleration pulse. Consequently, it is necessary to keep in mind that the deceleration pulse in the FWDB test was substantially different from the vehicle-to-vehicle test.

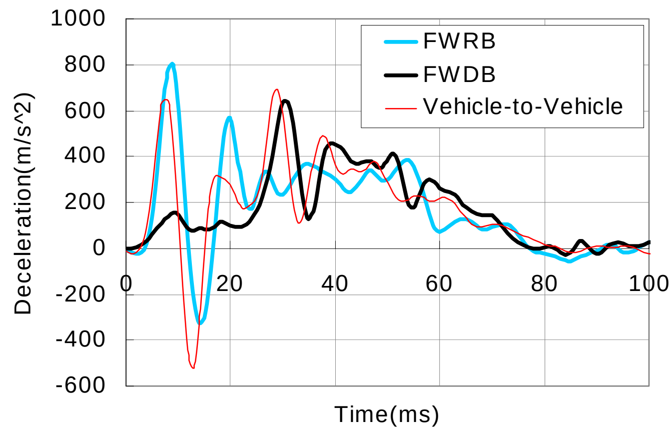

Figure 15. Deceleration-Time History

Overall the FWDB test is more beneficial than the FWRB test in terms of evaluating structural compatibility. Results from such tests might be used to design longitudinal members that balance self-protection considerations with crash interaction considerations.

MDB-TO-VEHICLE TEST

A Moving Deformable Barrier (MDB) test is currently one test method used to simulate vehicle-to-vehicle crashes from the dual perspective of body deceleration characteristics, which control occupant injury severity, and occupant compartment space [6][7]. The MDB test allows the mass ratio effect to be taken into account, and it can generate a realistic delta V and vehicle deceleration pulse. One of the goals for using the MDB is to study vehicle-to-vehicle crash response, deformation and occupant kinematics.

In order to simulate a vehicle-to-vehicle test, it is necessary for the Deformable Barrier (DB) to approximate the crush characteristics of actual vehicles. In this research, the use of the load cell data obtained from a full width barrier test was used to make a custom-built DB that consisted of aluminum honeycomb elements. First, the Force-Displacement characteristic in the FWRB test was transformed into the Pressure-Displacement (P-D) characteristics. Total barrier force was divided by the load cell area to generate a P-D curve.

The P-D curve was the basis for assigning crush characteristics to the DB. The A-type of the stiffness for the DB consisted of the 3 stages of constant pressure; 0.3, 0.6, and 1.0 MPa. The B-type was a constant level pressure of 0.7 MPa, with 700 mm of crush depth to prevent bottoming out. The A-type DB was designed to represent the large passenger car and the B-type DB is designed to represent an SUV. See Figure 16.

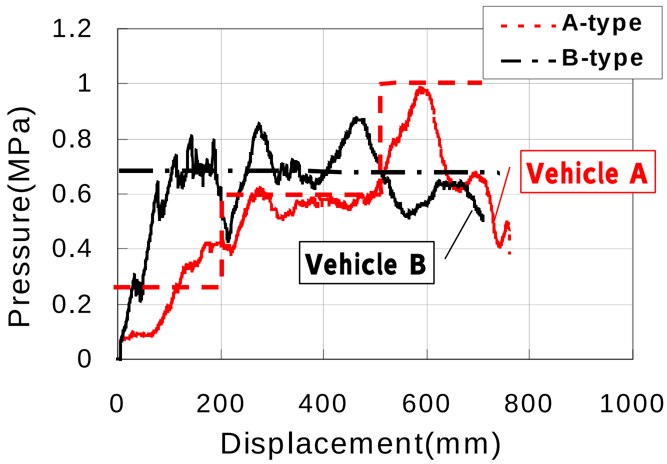

Figure 16. Pressure-Displacement Curve

A series of MDB-to-vehicle impacts was conducted to determine how well they compared to vehicle-to-vehicle test. See Figure 17. The MDB mass was set to correspond to the modeled vehicle. The A-type DB was attached to a 1900 kg MDB representing the large passenger car and the B-type DB was attached to a 2200 kg MDB representing the SUV. Each MDB was crashed into a compact sedan in 40% offset at 50 km/h. Hybrid **III** 50th percentile male dummies were used to study the injury levels for the driver and passenger positions.

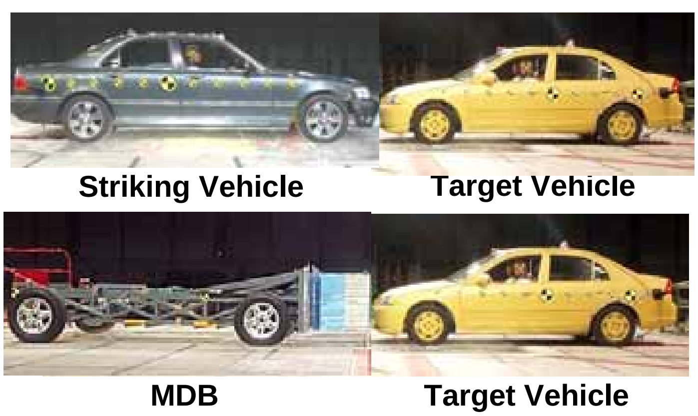

Figure 17. MDB-to-Vehicle Test Configuration.

The vehicle deceleration pulse and the chest deflection pulse for the driver in the target vehicle are shown in Figures 18a, b, c, and d. Those pulses in the MDB 40% test was generally similar to those in the vehicle-to-vehicle 50% test.

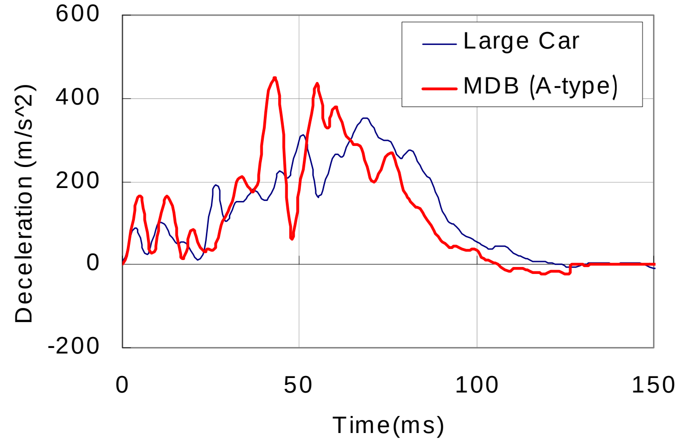

Figure 18a. Vehicle Deceleration Pulse (Large Car)

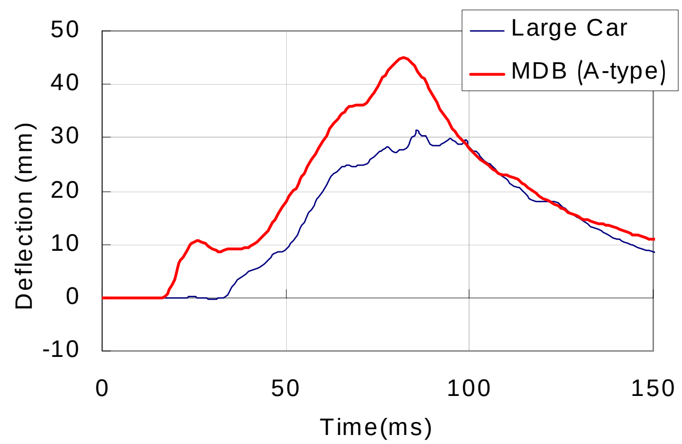

Figure 18b. Driver Chest Deflection Pulse (Large Car)

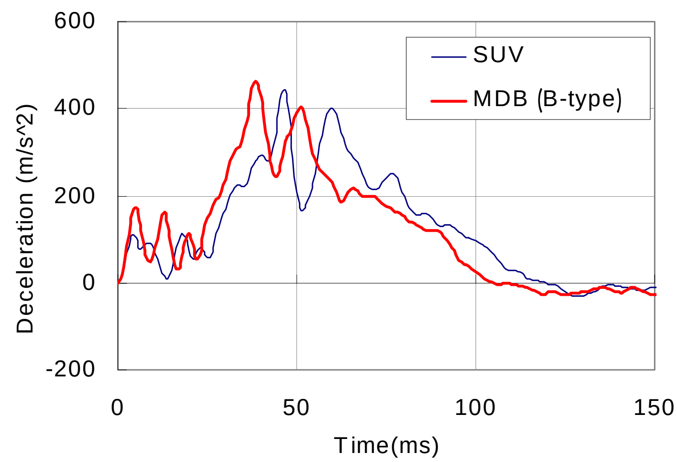

Figure 18c. Vehicle Deceleration Pulse (SUV)

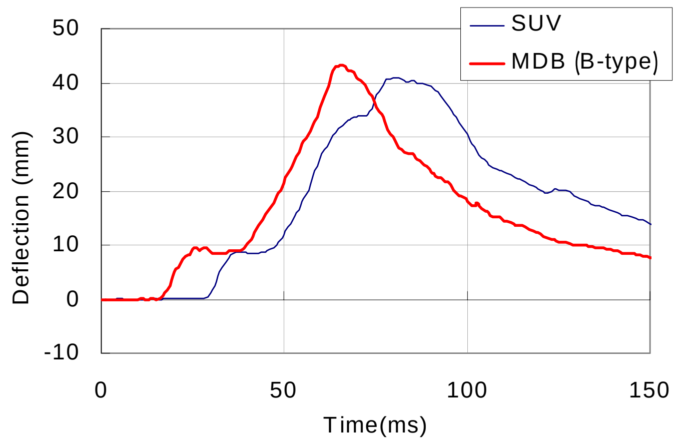

Figure 18d. Driver Chest Deflection Pulse (SUV)

Figure 19 shows the vehicle deformation. Fairly good fidelity was observed with regard to the vehicle deformation. However, this MDB test was slightly more severe than the corresponding vehicle-to-vehicle test.

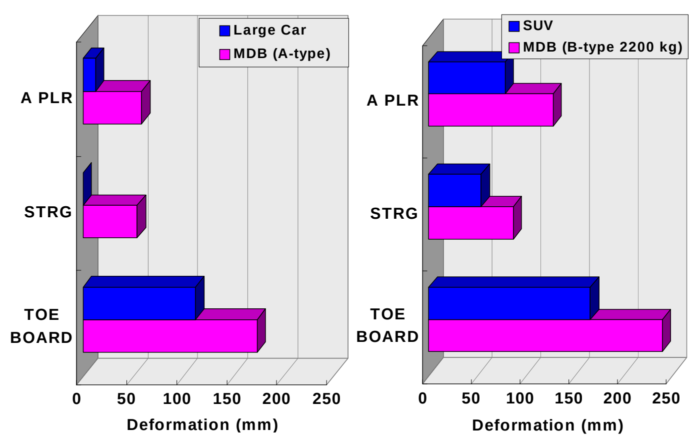

Figure 19. Body Deformation Comparison

Figure 20 shows the comparison of dummy responses for the target vehicle. Injury Assessment Reference Values (IARV) were used to normalize the injury measures. These reference values are defined in FMVSS 208.

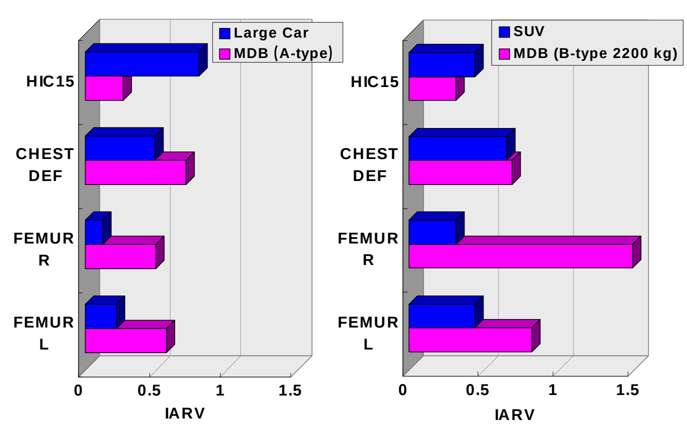

Figure 20. Injury Measures Comparison

The result of the MDB-to-car test shows that both the vehicle deformations and the injury measures were greater overall than those were in the vehicle-to-vehicle test.

STIFFNESS EXAMINATION

Higher injury and deformation levels were observed in the MDB test because the deformable face seems to be somewhat stiffer than the corresponding vehicle. It was pointed out in the previous section that the inertial mass of the hard structures affects substantially the load cell data in the FWRB test. Therefore the DB was improved by using the P-D characteristics in the FWDB test. See Figure 21. The stiffness of modified DB (C-type) was approximately half of the previous one (A-type).

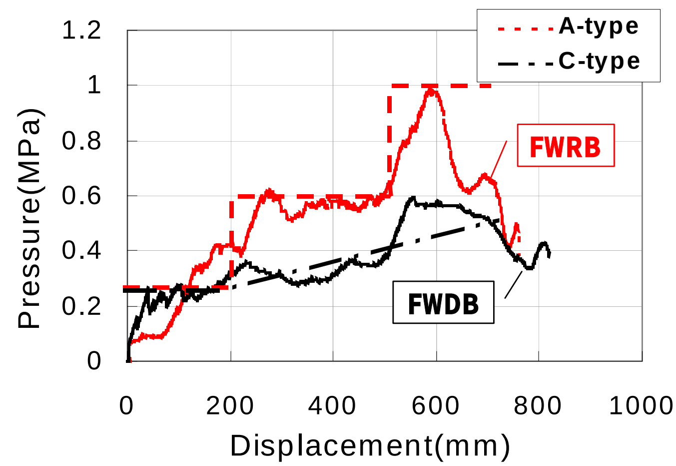

Figure 21. Modified Pressure-Displacement Curve

The C-type DB that was approximated by the P-D characteristics of the large car in the FWDB was used to carry out the MDB test. Compared to the A-type, the C-type showed slightly lower vehicle deformation and injury levels. See Figure 22. The peak time of the dummy chest deflection was similar to the vehicle-to-vehicle test than that in test 1. See Figures 23 and 24.

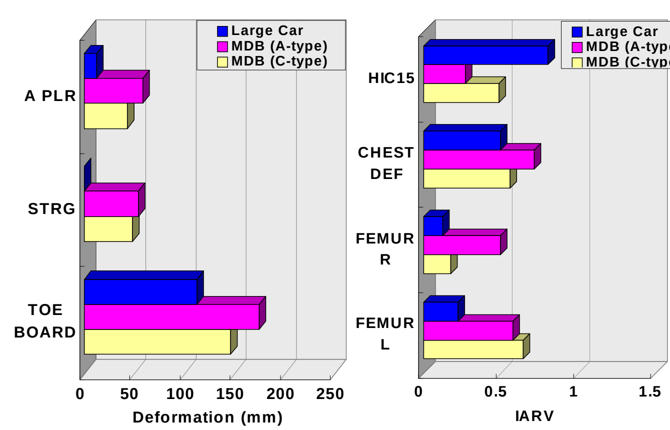

Figure 22. Test Results of the Modified DB

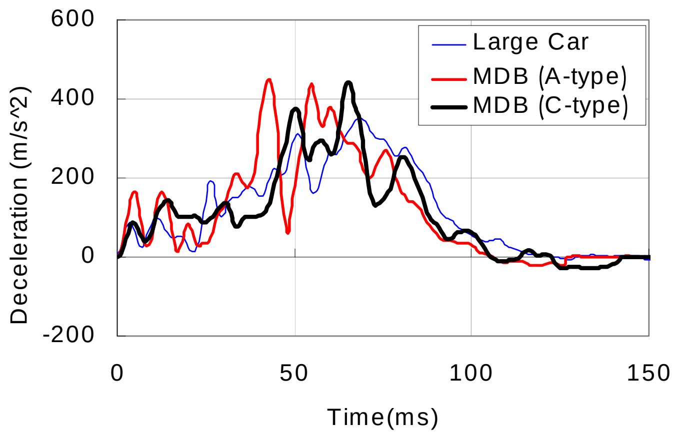

Figure 23. Comparison of Vehicle Deceleration Pulses

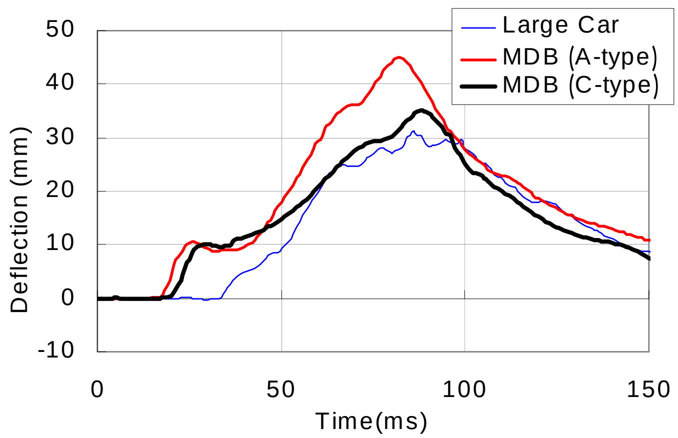

Figure 24. Comparison of Driver Chest Deflection Pulse

GEOMETRIC EXAMINATION

Two DB with identical masses and stiffnesses but different ground clearances were used in MDB-to-vehicle tests and the results were compared. No overriding was seen in the MDB test when the ground clearance of the MDB was adjusted to 150 mm. However, when the ground clearance of the MDB was adjusted to 280 mm of the same ground clearance as used in FMVSS 214 testing the MDB overrode the target vehicle. See Figure 25. The lower stiffness of the bottom edge of the DB in comparison with vehicle front structures contributed to the override in this MDB test. In addition, the cladding sheet of the DB gave a slope to its front surface. This deformation pattern might also have contributed.

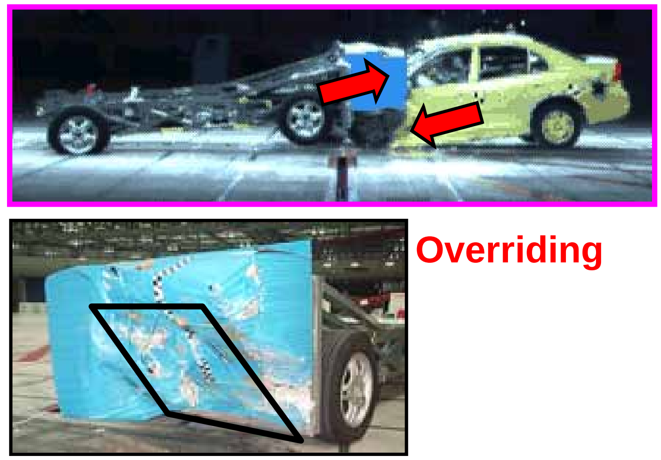

Figure 25. MDB Test with DB Ground Clearance at 280mm

MASS EXAMINATION

The effects of mass on injury risk have been studied for many years. In the MDB test, a ballast weight replaced the mass of the dummies. Therefore, the energy absorption by the seat belt and the pitching of the striking vehicle were neglected. It is possible that the exchange of mass influenced the vehicle deformation and the injury measures of occupant dummies. Therefore, the mass of the MDB was decreased from 2200 kg to 2000 kg and the MDB test was run again with all other test conditions unchanged. The B-type DB with the constant level pressure of 0.7 MPa was used to eliminate the stiffness effect in these tests.

In spite of the weight difference of 200 kg, vehicle deformation was similar between the two tests. See Figure 26. These results showed that the mass was not sensitive to the deformation and the injury measures in these tests. In addition, good correlation was observed in the vehicle deceleration pulse. See Figure 27. The deceleration pulses in the target vehicle in these tests should be the same except for the later stages of the impact due to the use of identical DB. Although concerns about repeatability of an MDB test are pointed out, overall good fidelity was observed in these test results.

Attachment 11

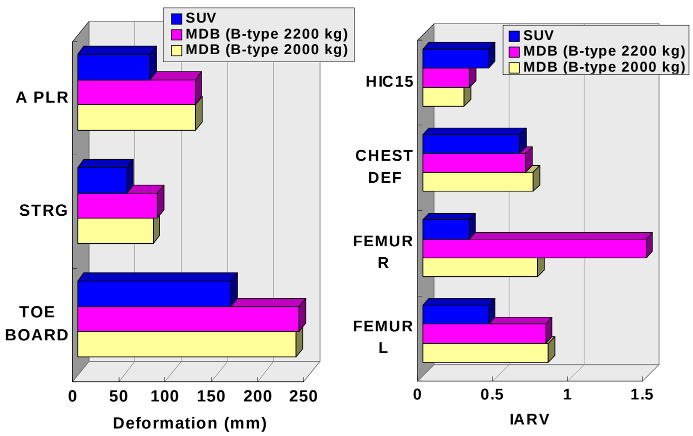

Figure 26. Comparison of Vehicle Deformation and Injury Measures

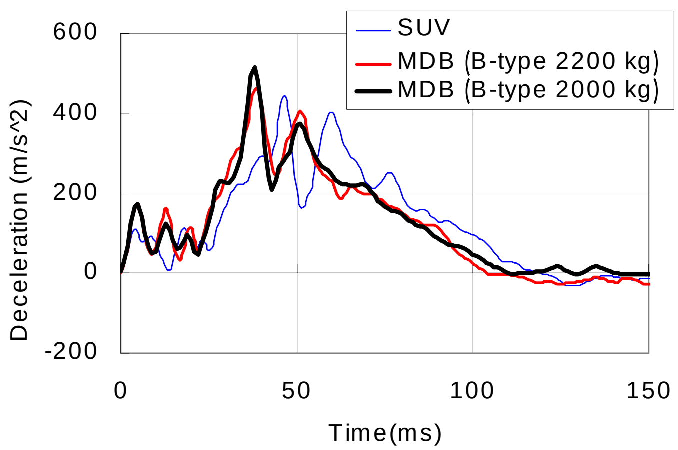

Figure 27. Comparison of Vehicle Deceleration Pulse

DISCUSSION

Testing of compatibility should evaluate the characteristics that can be change to enhance compatibility in frontal impacts. According to the IHRA report, structural interaction, frontal stiffness, passenger compartment strength, and deceleration pulse are important issues for compatibility. One way in which engineers might enhance crash interactions is to control crash area and stiffness. The authors submit that managing minimum and maximum interaction forces within the interaction area may be promising. The minimum force may minimize overriding and the maximum force would enhance stiffness matching in frontal impacts.

When interaction forces are determined, barrier load data in the FWDB test may simulate vehicle crash characteristics better than that in the FWRB test. However barrier load depends on the stiffness and the depth of the honeycomb element. Therefore, it must be noted that the deformable face has greater potential for a more realistic simulation.

SUMMARY

This report has examined test procedures for frontal collision compatibility in an experimental evaluation.

1. Vehicle frontal crash interaction (sometimes referred to as “ vehicle aggressivity”) is strongly affected by the vehicle crush characteristics of the vehicle front-end structure. A full width barrier test with load cells can provide the vehicle crush characteristics quantitatively. In order to assess self-protection performance, the MDB-to-vehicle test can provide a more realistic simulation in terms of vehicle and occupant kinematics. This is especially true of the deceleration pulse. Combining the full width barrier test and the MDB test may provide enhanced compatibility as proposed in the IHRA.

2. In the FWRB, barrier load cells pick up the inertial forces when large mechanical parts contact the rigid wall. These inertial forces may be misinterpreted and yield misleading information; therefore some kind of deformable elements would be necessary to attenuate these inertial forces.

3. In vehicle-to-vehicle tests, the deformation modes of the longitudinal members were similar to those in FWDB tests. Compatibility metrics should be evaluated under realistic deformation modes. Thus, the FWDB would be more favorable than the FWRB with regard to the structural assessment of the compatibility. However, the deceleration pulse in the early stages of the impact was considerably different between the vehicle-to-vehicle test and the FWDB test.

4. A deformable barrier (DB) for the MDB tests was developed using load cell wall data from both the FWRB test and the FWDB test representing vehicle crush characteristics. It was found from the results that the deformation of the target vehicle was greater when the DB developed by the FWRB was used. The rigid barrier test may generate some higher crush forces on the LCW. The DB developed by the FWDB test created more reasonable vehicle deceleration pulses and deformations.

5. In this study, stiffness of the MDB was a more dominant factor than the mass of the MDB in respect to vehicle deformation. Furthermore, the stiffness in the lower half of the DB affected the proneness of overriding. Thus, the stiffness distribution of the DB in the MDB test may control key characteristics of the compatibility.

6. MDB-to-vehicle tests were conducted with 3 types of deformable barriers and overall good correlation was seen between the vehicle-to-vehicle test and the MDB test. The MDB provides more flexibility for crash testing and would offer the best overall coverage of real world accidents.

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Attachment 12

THE OFFSET CRASH TEST -A COMPARATIVE ANALYSIS OF TEST METHODS

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Paper Number 98-S1-O-08

ABSTRACT

This research will discuss the issue of how the currently used frontal crash tests correlate to actual accidents. The following data will be presented in relation to this:

1. Results of offset crash tests now being conducted, and results of vehicle-to-vehicle crash tests, especially results of crash tests in which the vehicles have different weights.
2. Why do such differences occur?
3. Differences between the results of tests with moving deformable barriers (MDB) which are being studied by the National Highway Traffic Safety Administration (NHTSA) and results of vehicle-to-vehicle crash tests.
4. Results of modifications to test methods

The following aspects of the above mentioned issues will be discussed:

1. Important items and information to be considered in studying crash test methods to be used in the future.
2. Information which needs to be taken into consideration in developing cars in the future.

INTRODUCTION

In response to the need to improve crashworthiness, various countries have proposed and implemented a variety of test methods in order to provide regulations and safety information. Recently, offset crash tests have come into widespread use in addition to full frontal crash tests or oblique impact tests. In actual accidents, chassis deformation and intrusion into the cabin has been observed in many cases. In addition, passenger deaths have been reported in conjunction with chassis and cabin deformation. Therefore, with the primary objective of securing cabin space and thereby reducing passenger deaths, a great deal of research has been conducted on offset crash tests, as well as on the body frame structure in order to improve passenger survivability. Full frontal crashes are considered useful for evaluating the performance of safety devices which restrain passengers during a crash. Offset crashes are considered appropriate for evaluating cabin deformation caused by the impact loads on the vehicle during a crash. As has already been described in a wide range of literature on the subject, in a certain sense, these two test methods involve evaluating mutually contradictory phenomena. This is an extremely serious and difficult problem for automobile development engineers who are attempting to improve crashworthiness. Issues which will be critical in discussions of vehicle crashworthiness in the future are:

(1) Does each of these evaluation techniques provide methods and criteria which are suitable for increasing vehicle crashworthiness?

(2) Which of these test methods is useful in developing and evaluating a vehicle?

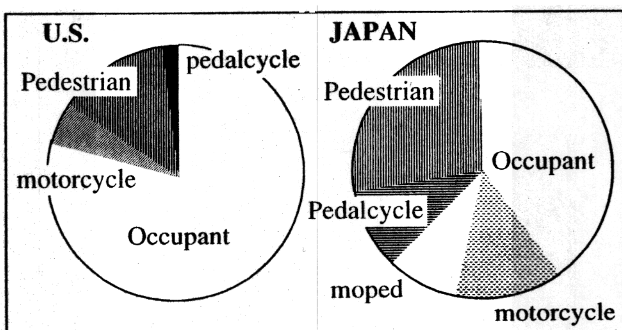
A variety of configurations and conditions have been proposed, especially for offset crashes, so further research and discussion are needed.

An area which is currently a main focus of concern is the types of considerations that are needed for vehicle designs which will provide compatible crashworthiness for both small cars and large cars. This issue is especially important for vehicles which are evaluated with these methods.

This research seeks to verify how crash test methods, either full frontal or offset frontal crashes, are associated with actual accidents. This research also discusses what needs to be done in the future.

BACKGROUND

Among actual accidents, deaths of passengers riding in vehicles may be classified as shown in Figure 1 for Japan and the U.S.



Sources: US; FARS 1995
JAPAN; The Japanese police traffic accident statistics since 1995

Figure 1. Fatalities in traffic accidents

Fatalities of passengers riding in vehicles may be further categorized by the type of accident. There are two general classifications: single-vehicle accidents and vehicle-to-vehicle accidents. The breakdowns for these classifications are shown in Figure 2. As shown in the figures, about half of the accidents are single-vehicle accidents and the other half are vehicle-to-vehicle accidents.

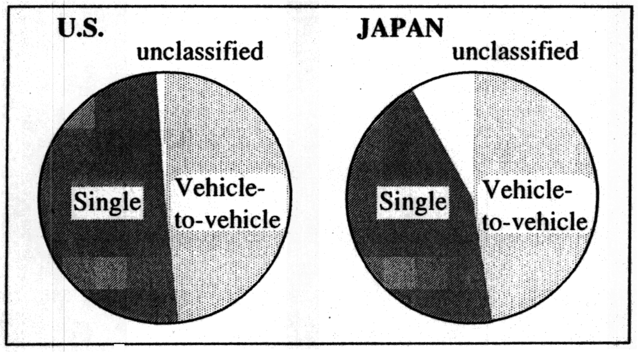
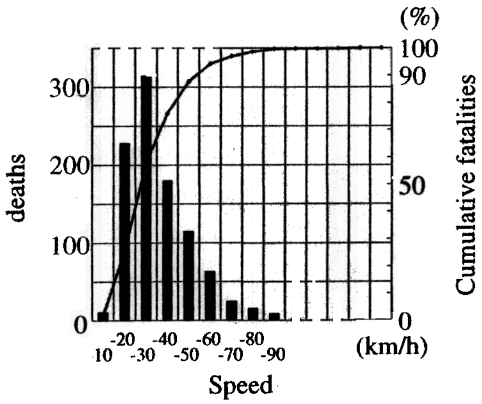


Figure 2. Classification of fatal collisions

Figure 3 presents the numbers of cumulative fatalities and the corresponding barrier equivalent speeds.

Approximately 90% of the cumulative fatalities occur at speeds of 50-55km/h or less.



Source: NASS CDS 1991-1995
head on collisions with belted

Figure 3. Barrier equivalent speed

The conditions for the tests currently being conducted were established based on such information.

We will now consider which types of actual accidents each of the test methods is applicable to. The discussion will be simplified in order to maintain a comprehensive focus on current problems and future trends. For further information on the detailed verifications, the reader is referred to the results of research conducted by various researchers in the course of establishing each of the crash test methods. The frontal crash test methods which are currently used in Japan, the U.S., Canada, Europe, and Australia are listed in Table 1.

Table 1. Test configurations

	JAPAN	U.S.	EUROPE	AUSTRALIA
Regulation	Full flat 50km/h	Full flat 48km/h R/L 0°~30° 48km/h	ODB 56km/h	Full flat 48km/h
Consumer safety information test	Full flat 55km/h	Full flat 56km/h ODB 64km/h	ORB 55km/h ODB 64km/h	Full flat 56km/h ODB 64km/h

The common types of full frontal crash tests into a flat, rigid barrier, are the regulation tests used by the NHTSA in the U.S., Transport Canada in Canada, the Federal Office of Road Safety (FORS) in Australia, and the Ministry of Transport in Japan. This same type of test is also used in the New Car Assessment Program (NCAP), which serves to provide consumer safety information and incorporates some changes (e.g., a higher crash speed). These test methods will now be considered in relation to actual accidents. In vehicle-to-vehicle accidents, vehicles of the same weight may collide head on with almost no offset. In single-vehicle accidents, the vehicle may collide head-on into an object such as a structure. In actual accidents where the vehicle collides into a structure, vehicles may collide into trees, utility poles, or experience under-ride impact into trucks in addition to colliding into flat objects. At the present time it is very difficult to narrow down correlation with macro data. It is difficult to postulate the exact extent to which this test method covers actual accidents. However, it is possible to infer from the statistics on cumulative fatalities that there are cases in which passengers are subjected to rather strong impacts during collisions.

In light of such considerations, the full frontal rigid barrier crash test methods seem extremely useful for evaluating life saving capabilities which would reduce passenger injuries during extremely strong actual impacts. This test method is advantageous in that it allows evaluations under conditions in which driver and passenger impact severities are nearly identical. The offset crash tests conducted in the past few years may be broadly divided between offset rigid barrier (ORB) crash tests and offset deformable barrier (ODB) crash tests.

In the case of offset rigid crashes, offset crashes between vehicles of the same weight during vehicle-to-vehicle accidents and offset crashes into structures during single-vehicle accidents are covered by this method and are considered applicable. However, as in the case of full frontal crashes, there is not a clear association between offset rigid crashes and collisions into trees or utility poles, or under-ride impact into trucks.

In the case of offset deformable crashes, the results of experiments replicating vehicle-to-vehicle accidents have been used to establish test conditions, such as collision speed and the specifications of the honeycomb (a deformable device), as has been referred to in European Experimental Vehicle Committee (EEVC) and Insurance Institute of Highway Safety (IIHS) research reports. However, there has been little in the way of verification under conditions in which the vehicles involved have different weights. Therefore, in this study we would like to compare the results of such offset deformable crashes with the results of vehicle-to-vehicle tests based on vehicles with different weights. The need for verification using offset crash tests is to determine how well passenger space in the vehicle cabin is protected. This test serves to evaluate cabin deformation, and resistance to intrusion as a result of the collision. Thus, this method can be used to verify how well the cabin and frame in the engine room compartment are able to absorb the impact energy from the collision and distribute the impact forces. As reported in the for EEVC and IIHS research reports, the specifications of the offset deformable barrier (honeycomb) which is used with this test simulates the stiffness of the structure at the front of a vehicle of nearly average weight (normally called a mid-size vehicle). In terms of actual vehicle-to-vehicle accidents, this test seems to simulate vehicle-to-vehicle collisions involving vehicles of average weight or less.

TEST RESULTS

Actual vehicle crash tests were conducted under these offset conditions. Figure 4 illustrates the vehicle deformation results of offset rigid collisions. The offset rigid crash test method (ORB) was used by Auto Motor Sport, a German magazine. Figure 5 illustrates the vehicle deformation results of offset deformable collisions.

Figure 6 compares the deformation results of vehicle-to-vehicle offset crash tests in which both vehicles weighed approximately 1500kg. The vehicle-to-vehicle crash test conditions were a speed of 56km/h for both vehicles and an offset of 50%

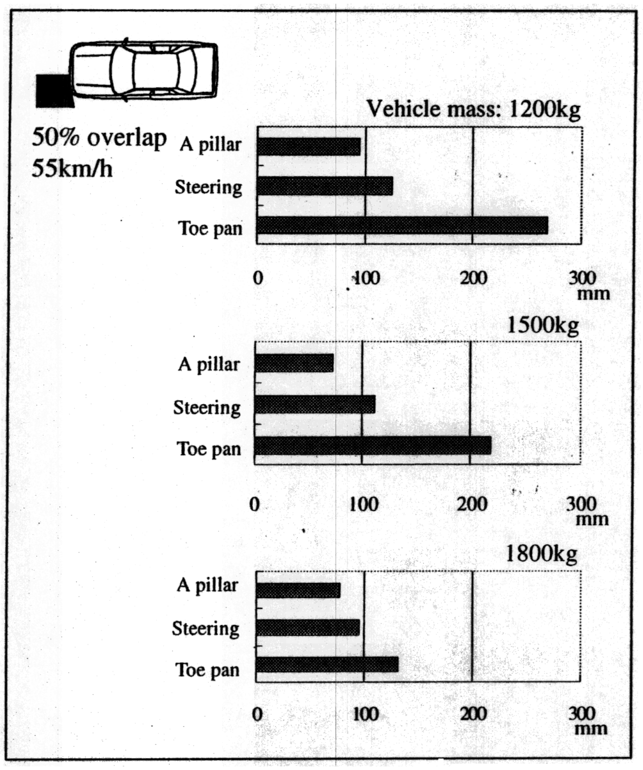


Figure 4. Vehicle deformation (ORB)

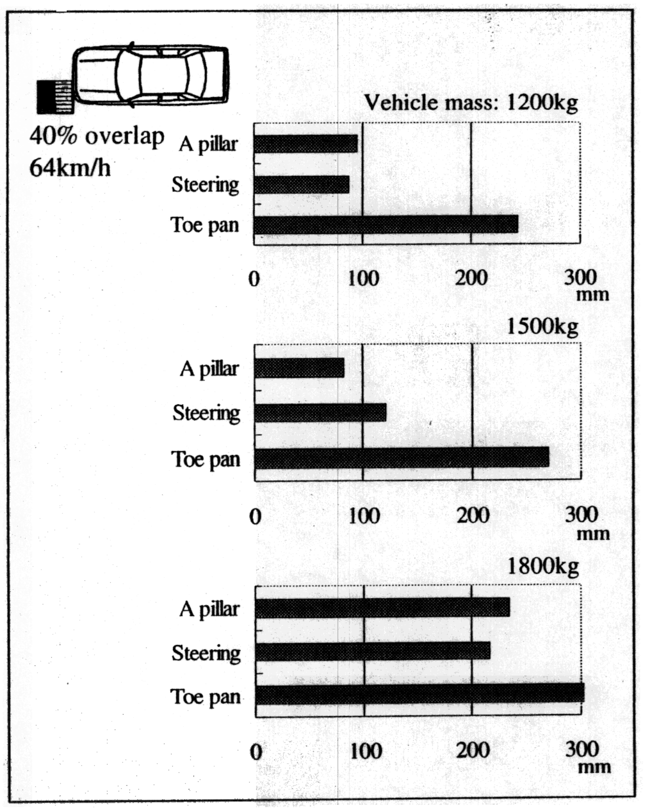


Figure 5. Vehicle deformation (ODB)

Attachment 12

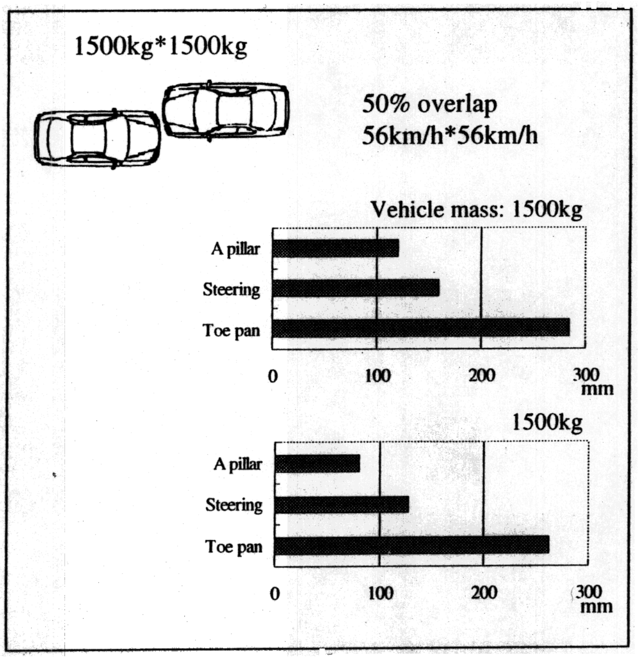


Figure 6. Vehicle deformation (vehicle-to-vehicle)

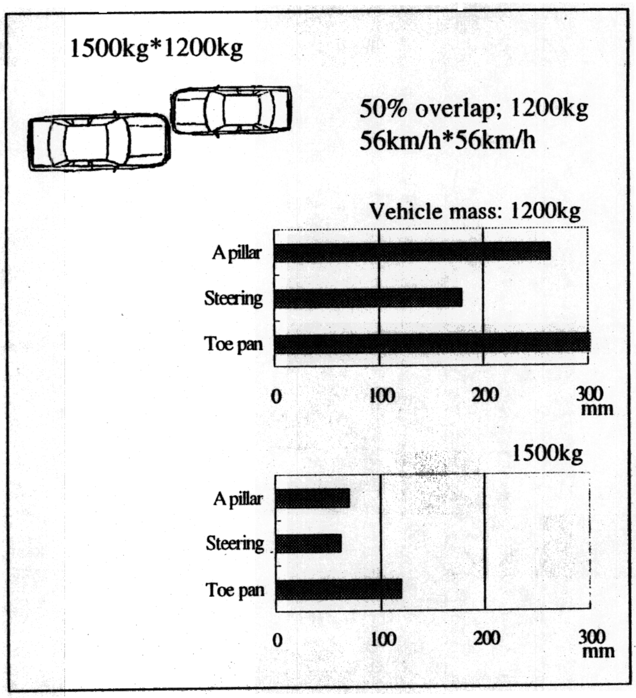


Figure 7. Vehicle deformation (vehicle-to-vehicle)

Figure 7 compares the deformation results of the same type of vehicle-to-vehicle offset crash tests in which one of the vehicles weighed approximately 1200kg, and the other approximately 1500kg.

Figure 8 compares the deformation results of the same type of vehicle-to-vehicle offset crash tests in which one of the vehicles weighed approximately 1200kg, and the other approximately 1800kg.

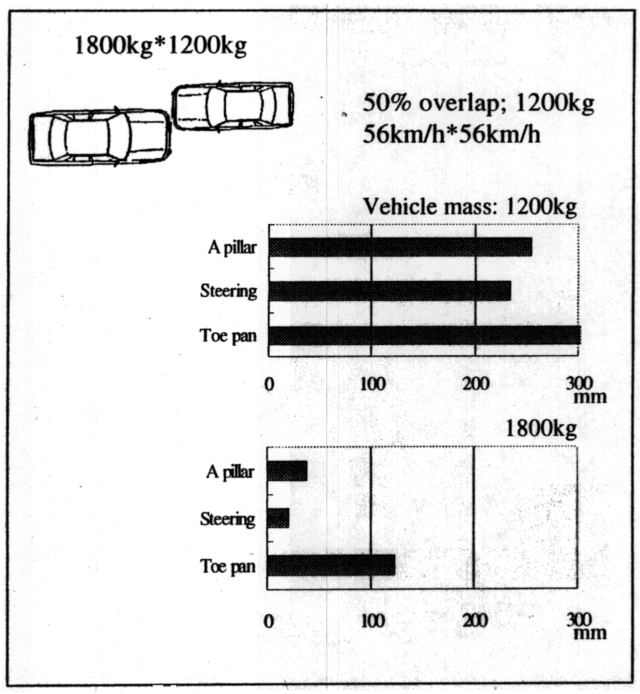


Figure 8. Vehicle deformation (vehicle-to-vehicle)

ANALYSIS

As illustrated above, the results for vehicle-to-vehicle offset crash tests in which both vehicles weighed approximately 1500kg were consistent with the offset deformable crash test results. When the vehicles had different weights, there is a significant difference between the vehicle-to-vehicle crash test results and the barrier crash test results.

As mentioned above, offset rigid barrier collisions simulate collisions between vehicles of the same weight, or collisions into structures. In contrast, offset deformable barrier collisions are essentially offset collisions between vehicles of average weight. However, the results of the offset deformable barrier crash tests indicate that if the colliding vehicle weighs more than average, (e.g.,1800kg) a bottoming out phenomenon will occur due to the characteristics of the deformable barrier (i.e., the honeycomb). As a result it would seem that an actual vehicle-to-vehicle crash is not simulated in such cases. Similar problems have already been pointed out among researchers; this will remain a topic for future study.

Nonetheless, this cannot be set aside as a simple "issue". In other words, vehicles which are developed in order to obtain good evaluation results using such test methods may create a number of problems under actual road conditions.

One such problem is an increase in vehicle weight. It is inevitable that weights will increase as a result of improvements in crashworthiness. Unfortunately, excessive increases in vehicle weight remain a significant problem. Specifically, vehicles whose structures are designed based on test conditions and evaluation criteria which are significantly different from actual accident conditions will not contribute appropriately to efforts to improve crashworthiness under actual road conditions. Also this is a problem of compatibility in vehicle-to-vehicle crashes. Along with the need to protect the vehicle of a person driving in mixed traffic, it is also necessary to protect the other vehicle in an accident. This capability may be an important issue in the future. Among actual accidents, total fatalities are divided approximately evenly between single-vehicle accidents and vehicle-to-vehicle accidents. It is necessary to protect passengers in both of these types of accidents. In particular, during vehicle-to-vehicle collisions, it is necessary to consider the safety of the other driver -- not just the driver in the car which is being designed. Results from the vehicle-to-vehicle crashes of different weights specifically show this problem. Figure 9 illustrates this phenomenon graphically. As vehicle weight increases, the stiffness of the vehicle front increases.

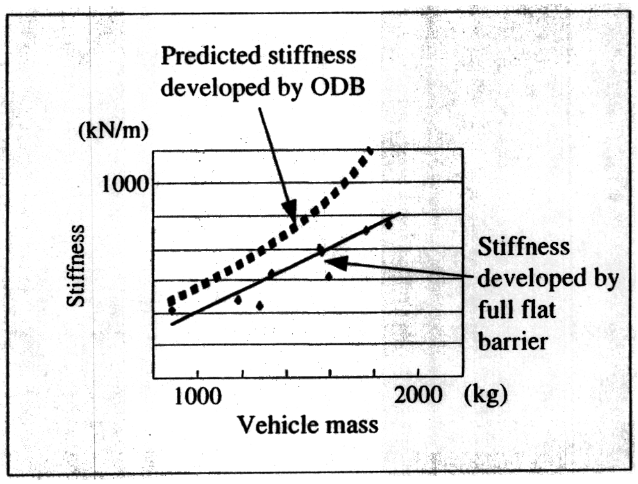


Figure 9. Prediction of stiffness

The test results done on each vehicle in the U.S. with an NCAP full frontal barrier show a strong correlation between vehicle weight and stiffness. In other words, an increase in vehicle weight can be inferred to lead to an increase in aggressiveness toward the other vehicle. As used here, the term 'vehicle stiffness' is defined as the slope of the load on the chassis as derived from an accelerometer attached to the cabin floor on the chassis. Figure 10.

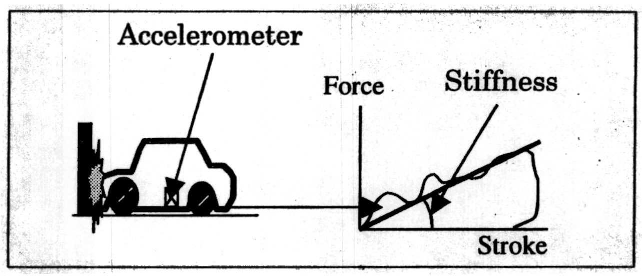


Figure 10. Definition of vehicle stiffness

Next we used same-weight vehicles as described above to verify the recent test method of the U.S. NHTSA, which is being researched based on vehicle-to-vehicle crashes. The 56km/h vehicle-to-vehicle crash results are shown in Figure 11.

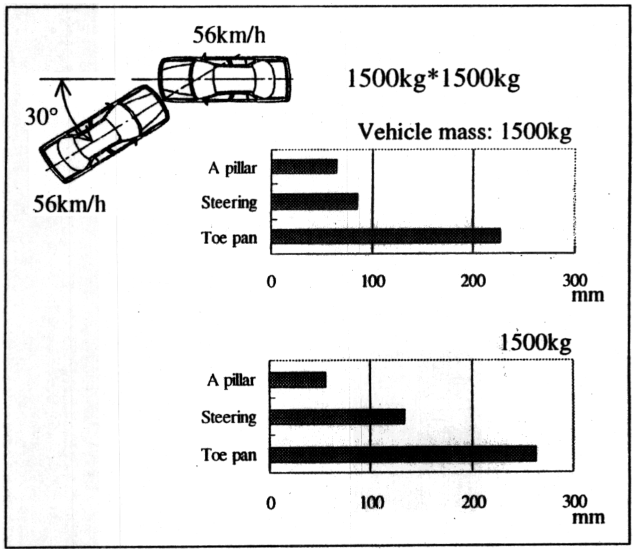


Figure 11. Vehicle deformation (vehicle-to-vehicle)

Figure 12 illustrates the results of a stationary vehicle crash test using a 112km/h moving deformable barrier (MDB).

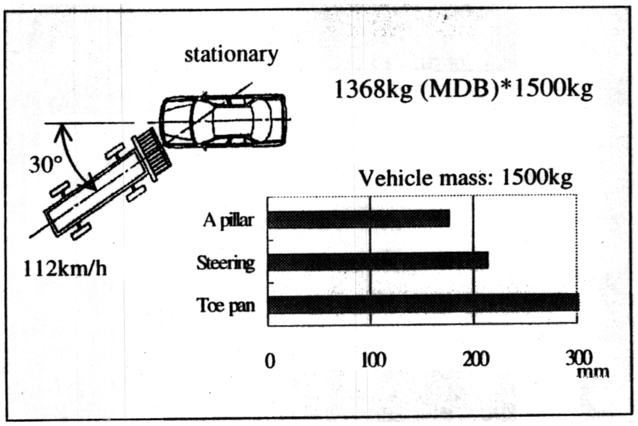


Figure 12. Vehicle deformation (vehicle-to-vehicle)

As indicated by the diagram, this test method clearly involves a vehicle-to-vehicle type of accident. One way it is different from the frontal offset crashes discussed thus far is that the offset is oblique. The second is to use an MDB. The MDB weighs 1368kg, which is the average vehicle weight in the U.S. This method appears to be based on the type of accident which is likely to occur frequently under actual road conditions. Note that the NHTSA research results should be checked for details regarding what types of actual accident situations are covered. As illustrated in Figures 11 and 12, a comparison of deformation amounts in the vehicle which is collided into shows that deformation for MDB and a vehicle is much greater than deformation between one vehicle and another.

One reason for this can be clarified by comparing the amount of deformation in the deformed area on the colliding vehicle. This comparison shows that there are problems in the characteristics of the barrier, i.e., the honeycomb, similar to the results for the offset deformable crash tests. As in the EEVC and IIHS tests, this problem seems to be due to honeycomb bottoming out, i.e., the stroke is significantly different than that of actual vehicles. Figure 13 illustrates the force (deceleration) vs. displacement characteristic in an actual vehicle compared to the results obtained in a test using a honeycomb.

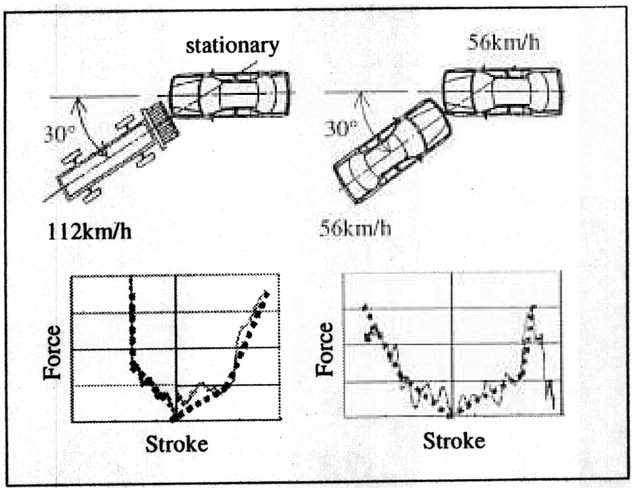


Figure 13. Comparison of Force-Stroke characteristics

Figure 13 also indicates a clear difference between the results. Assuming the collision speed simulation parameter is physically and theoretically correct, the honeycomb characteristics are a definite problem with this test method. This test method has other problems as well: reproducibility and practicality. Since this test method involves an oblique crash test, there is inconsistency in the amount of offset. And it is almost impossible to conduct the high MDB test speed in an ordinary indoor laboratory, so it is not well suited to third-party evaluation tests, including compliance. Then a test method which would theoretically solve the problems discussed above was devised. This test method, illustrated in Figure 14, was developed with consideration for reasonableness, faithfulness, reproducibility, practicality, and aggressiveness evaluations.

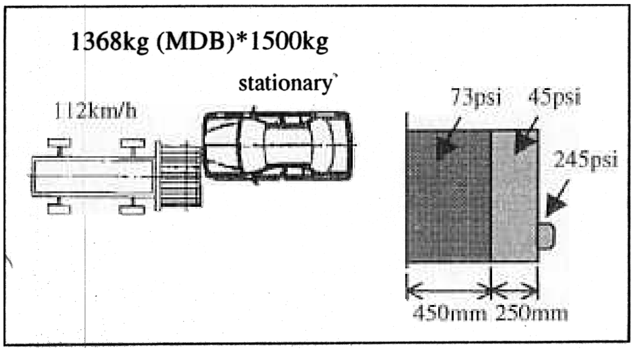


Figure 14. Test method of MDB-to-vehicle

Like NHTSA, for the MDB we selected the average weight which was most likely to be encountered under actual road conditions. We tried using a compound honeycomb consisting of a honeycomb which is average or has a hardness that is nearly the same as the stiffness of the engine rooms of vehicles which are commonly sold in the U.S., plus a honeycomb with stiffness characteristics similar to cabin stiffness. A relative MDB speed between 100km/h and 120km/h would simulate vehicle-to-vehicle collision speed of approximately 56km/h. In this test we used a speed of 112km/h. In order to minimize inconsistency in the data caused by the test method, we decided to make the collided vehicle stationary in a frontal offset collision. Some evaluations may consider an oblique collision to have a better correlation to actual road conditions, but oblique collisions were not used in this test. The test results are shown in Figure 15.

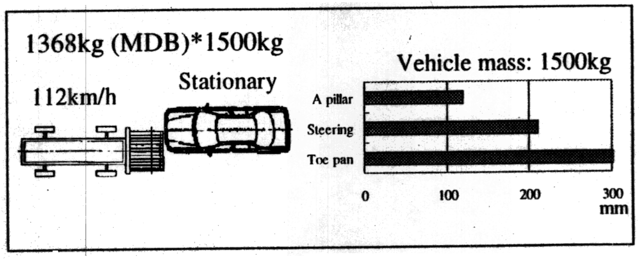


Figure 15. Vehicle deformation (MDB-to-vehicle)

The vehicle deformation approaches the test results in Figure 15, but the amount of deformation for the steering wheel is still larger. This seems to be due to the fact that the MDB rose onto the collided vehicle. There are two further problems with this test method. One is that it does not solve the difficulty of conducting the test in an ordinary indoor laboratory. The second problem is that the use of a compound honeycomb comprising two different honeycomb types makes it necessary to verify whether the method is acceptable in terms of production technology (including reproducibility), and whether the desired characteristics can be obtained.

CONCLUSION

The offset deformable barrier tests currently conducted using honeycombs are suitable for evaluating vehicle safety in vehicle-to-vehicle accidents involving vehicles which weigh approximately 1500kg or less. However, the results are not necessarily consistent with actual accidents in cases where the vehicles weigh more than approximately 1500kg. This is due to a problem with the specifications of the honeycomb, which is the deformable device. Specifically, the force-stroke characteristic of currently used honeycombs is not suitable for vehicle-to-vehicle crash tests with vehicle weights of 1500kg or greater. Our results reconfirm the recognition and observation by others that this is a bottoming out problem. In addition, it was learned that vehicle-to-vehicle offset collisions involving an MDB are not necessarily consistent with actual accidents in terms of what actually happens (e.g., the MDB rises onto the test car). Therefore further research is needed.

DISCUSSION

As described above, test methods involving deformable barriers have been proposed and are used to simulate vehicle to vehicle accidents. However, based on these tests results, the barrier characteristics do not always seem to replicate actual accidents. In cases where there is a difference in weight between vehicles, as is commonly found in vehicle-to-vehicle accidents, the heavier vehicle will suffer less deformation than the lighter vehicle. This has been confirmed experimentally, so test methods which provide different results are clearly problematic in a number of respects. Specifically, there is the problem of the collision speed, which is not related to the vehicle weights, and the related honeycomb characteristics. In the future we believe it will be necessary to establish appropriate test methods based on further research.

Another problem which may arise is that vehicles which are developed using such problematic test methods may not be suitable in terms of compatibility in vehicle to vehicle collisions -- an issue which is expected to be important in the future. In particular, heavier than average vehicles which are sold in each market have the potential to increase aggressiveness toward small and lighter-weight vehicles.

This paper presents research on vehicle to vehicle tests involving an MDB, and compares these tests to ODB crash tests which are currently used. Further research will be needed in the future on criteria for evaluating vehicle aggressiveness.

Collision accidents are extremely complex. For this reason, it is necessary to have a number of methods for evaluating crashworthiness -- not just one method. In particular, it is impossible to use a single test method to evaluate mutually contradictory phenomena (i.e., single vehicle crash protection evaluations and securing cabin space in vehicle-to-vehicle crashes). Therefore, care must be taken in publishing test results supposedly serving as safety information.

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2. Offset Frontal Impacts - A Comparison of Real-World Crashes with Laboratory Tests. Brian O'Neill, Adrian K. Lund, David S. Zuby, Charles A. Preuss(IIHS) 1994 ESV 94S-S4-O-19
3. An Examination of Different Test Procedures for Frontal Offset Crashes. Sheldon L. Stucki, William T. Hollowell (NHTSA)

Attachment 13

INNOVATIVE BODY STRUCTURE FOR THE SELF-PROTECTION OF A SMALL CAR IN A FRONTAL VEHICLE-TO-VEHICLE CRASH

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Paper Number 239

ABSTRACT

Preservation of passenger compartment space during a frontal vehicle-to-vehicle collision is extremely significant for the self-protection of small cars.

It is well known that crash speed, mass, stiffness and geometric interaction all have an influence on the intrusion of the passenger compartment in a frontal impact between vehicles. This paper reports on a new enhanced body structure to reduce passenger compartment intrusion in a crash between large and small cars. The test discussed in this report set the crash speed of both cars at 50kph, the mass of the large car at almost twice that of the small car, and the small car over lap at 50%. The proposed innovative body structure for the front end of small cars achieved a previously unavailable level of efficiency of energy absorption and was able to maintain cabin integrity.

INTRODUCTION

In recent years the use of stationary barrier crash tests as a method of evaluation of crash safety performance has increased internationally. This has been very effective in improving vehicle crash safety performance and reducing the number of casualties in traffic accidents.

However, in the case of frontal collisions between small cars and large cars in the real world accident, it is said that the risk of injury to the small car's occupants is higher than that to occupants of the large car. This is caused by incompatibility between 'mass' 'stiffness' and 'geometry' in vehicle-to-vehicle collisions. A collision in which the mass and stiffness ratios of the vehicles are large is equivalent to an extremely high speed stationary barrier crash for a small car.

Small cars which receive good evaluations in full lap and offset frontal crash barrier tests are therefore not always sufficiently safe in a small car to large car collision in the real world accident. And it begins to be pointed out the necessity to have an another manner to evaluate it in the collisions with relatively different sized vehicles.

In particular in the case of narrow offset collisions in which overlap distance is relatively small in the direction of the vehicle's width and collisions with differing bumper height, it is very difficult for conventional body structures to maintain crash safety performance. It is therefore necessary to propose innovative body structures based on new design concepts. Of course it goes without saying that it is extremely significant for compatibility not only to consider the progress of self-protection but also partner-protection (for opposite vehicles). This research reports on the possibility to improve the self and partner protection which are discussed in the society by modifying the body structure such as one of the unique technique.

THE SAFETY IMPROVEMENT FOR SMALL CARS

In frontal vehicle-to-vehicle collisions it has been discussed that mainly 'mass' 'stiffness' and 'geometry' are the factors for incompatibility. In this part we report on some subjects and solutions in the view of the self-protection for small cars.

The portion of the velocity change before and after collisions is influenced by mass ratio as follows.

$$Vr = 1/Mr \qquad (1.)$$

$Vr = \Delta V_2/\Delta V_1$ ΔV_i: velocity change of Vehicle i $Mr = M_2/M_1$ M_i: mass of Vehicle i

The lighter vehicles are forced to a higher deceleration level than the heavier vehicles. As a result the risk of injuries in small cars is higher than in large cars. We will be able to solve such mass incompatibility developing superior restraint systems for small cars and to reduce mass in large cars.

The portion of energy absorption in vehicle deformation depends on stiffness ratio of two vehicles as follows.

$$Er = 1/Kr \qquad (2.)$$

$Er = E_2/E_1$ E_i: energy absorption of Vehicle i

$Kr = K_2/K_1$ K_i: stiffness of vehicle i

The problem is how to balance several vehicles' stiffness. To be realistic we need to improve the stiffness for small cars.

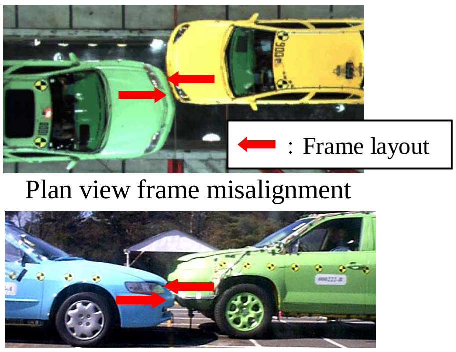
Certainly as stated above the difference between mass and stiffness is a problem for the compatibility, however we should first improve geometrical compatibility.

In recently years the level of self-protection for small cars has advanced greatly because of the adoption of offset deformable barrier testing. However the deformable barrier is very uniform in stiffness. But in reality, the front of vehicle in vehicle-to-vehicle collisions lack uniform stiffness, which causes severe damage to small cars. After this we focus on the improvement of interaction in frontal structures.

NEW DESIGN CONCEPT

To improve the offset and full lap frontal crash performance, conventional body structures are generally designed with two main frames located on each side of the engine compartment to absorb vehicle energy and to control vehicle deceleration.

However, in the case of vehicle-to-vehicle collisions such as narrow offset collisions in which there is less overlap distance in the direction of vehicle width and collisions between a passenger cars and a Sports Utility Vehicle (SUV) in which the bumper beam heights of the vehicles differ (as shown in Figure 1), this body type allows structural penetration into the engine compartment.



Plan view frame misalignment

Side view frame misalignment

Figure 1. Misalignment of stiffness between vehicles in vehicle-to-vehicle collision.

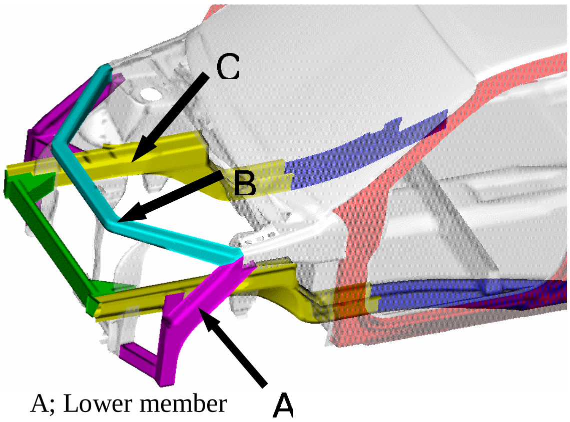
In particular when there is a significant difference in vehicle weight, the bumper beam and main frame of the large car passes into the frame of the small car without sufficient energy absorption and deceleration, penetrating the weaker part of the small car. As a result, deformation extends to the small car's passenger compartment, increasing injuries to occupants from secondary collisions in the passenger compartment, as shown in Figure 2.

It is important for the improvement of the level of protection offered by small cars to prevent structural penetration of major frontal components, increase the homogeneity of strength distribution and improve energy absorption in the engine compartment in the event of vehicle-to-vehicle collisions between vehicles with misalignment of stiffness. The design concept will be expected not only to achieve progress for self-protection but also the effect of partner-protection for compatibility.

Figure 2. Large deformation of the passenger compartment after narrow offset vehicle-to-vehicle collision.

STRUCTURAL OUTLINE AND CRASH PERFORMANCE

The proposed structure consists of three components, as shown in Figure 3.



A; Lower member
B; Closed bulk head upper cross member
C; Polygonal main frame

Figure 3. Structural outline.

These components are A; A lower member to prevent penetration. B; A closed bulk head upper cross member to assist energy absorption in the upper part of the engine compartment. and C; A polygonal main frame enabling high efficiency energy absorption. This paper will offer a structural outline of the lower member system and discuss the predicted effectiveness of this system as determined by computer simulations.

The new 'lower member' was positioned in front of the tires extending from the wheel house upper member, and was connected to the main frame and bulk head cross member. This prevents the penetration of the frames of the respective vehicles in narrow offset collisions and collisions between vehicles with differing bumper heights. (See Figure 4). On impact, the lower member makes contact with the front structure of the other vehicle and deforms, thus achieving a high level of energy absorption (as shown in Figure 5).

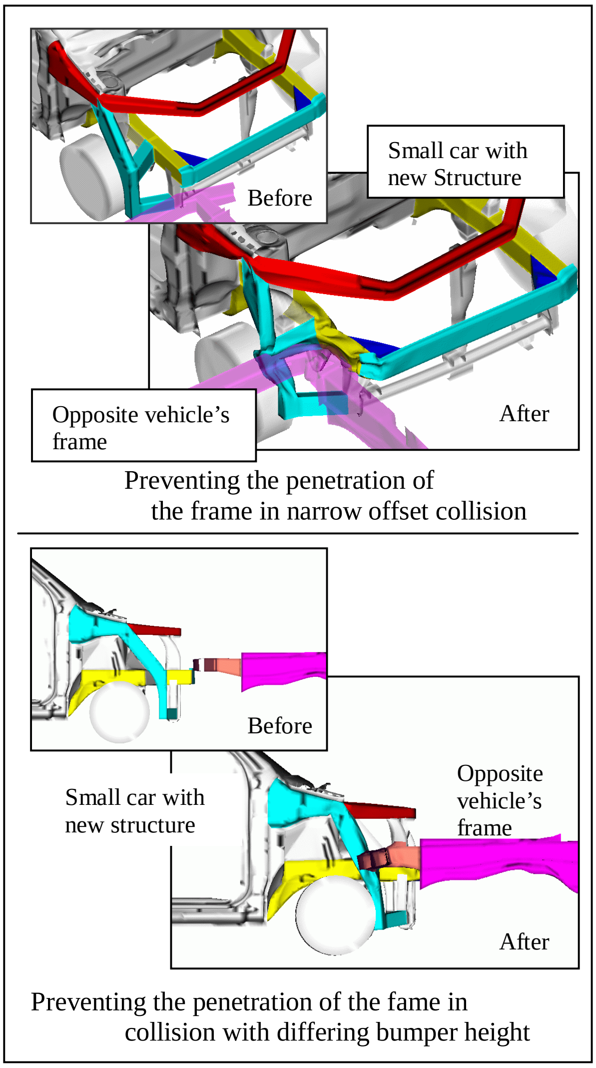


Figure 4. Preventing the penetration of the Frame.

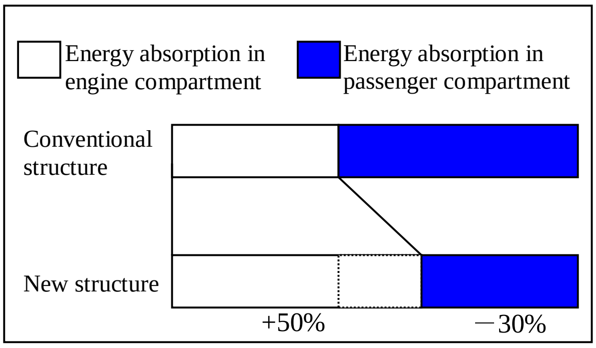


Figure 5. Increasing energy absorption in the engine compartment from vehicle-to-vehicle collision.

This leads to a significant reduction in the proportion of energy absorption in the cabin and of the degree of passenger compartment intrusion. The effectiveness of the new structure in reducing passenger compartment intrusion is shown in Figure 6.

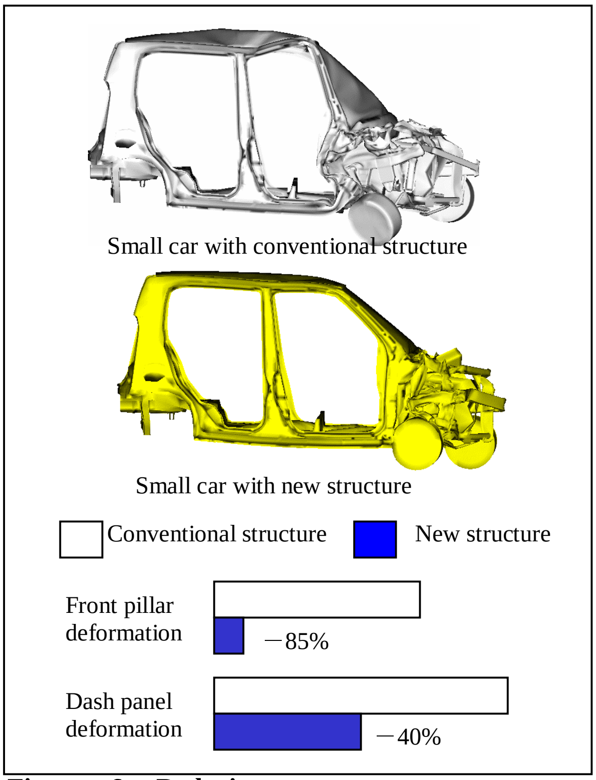


Figure 6. Reducing passenger compartment intrusion in vehicle-to-vehicle collision.

The new structure also enables reduction of the strength and weight of the main frame, allowing a more homogeneous distribution of strength in the front end structure.

It is predicted that this structure will be effective in reducing passenger compartment intrusion for various overlap distances in the direction of vehicle width (as shown in Figure 7), for the difference of bumper height (as shown in Figure 8) and for angle of approach (as shown in Figure 9).

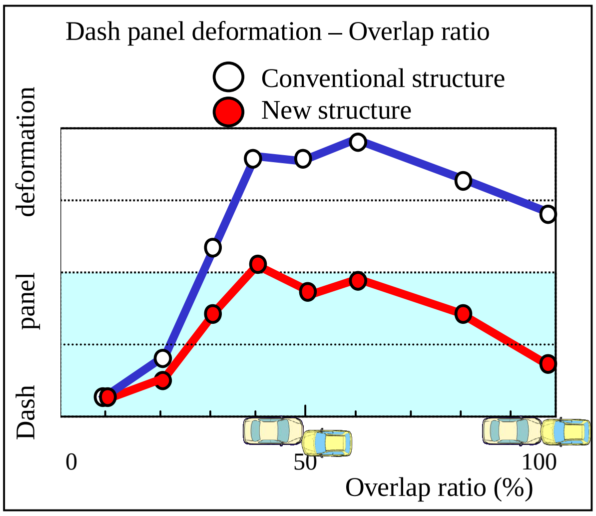


Figure 7. Reducing passenger compartment intrusion in various offset vehicle-to-vehicle collisions.

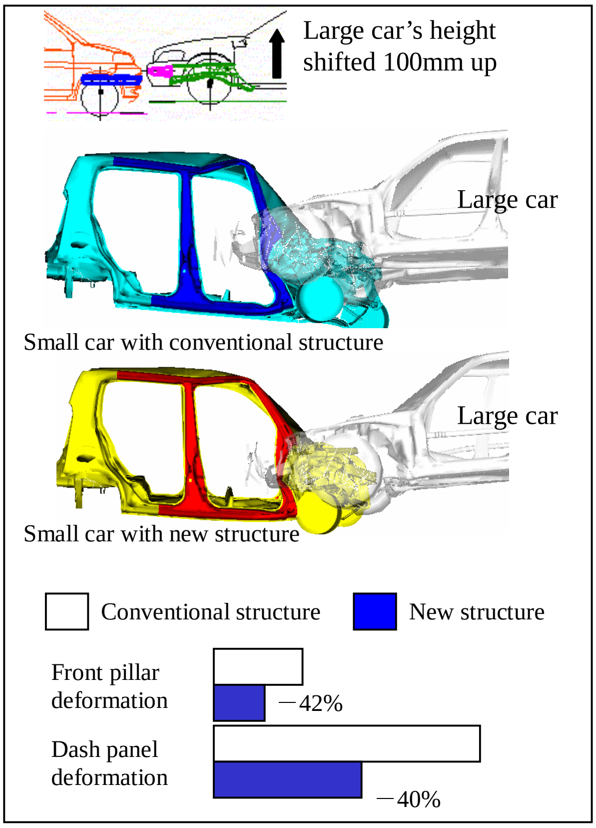


Figure 8. Reducing passenger compartment intrusion for vehicle-to-vehicle collisions with differing bumper height.

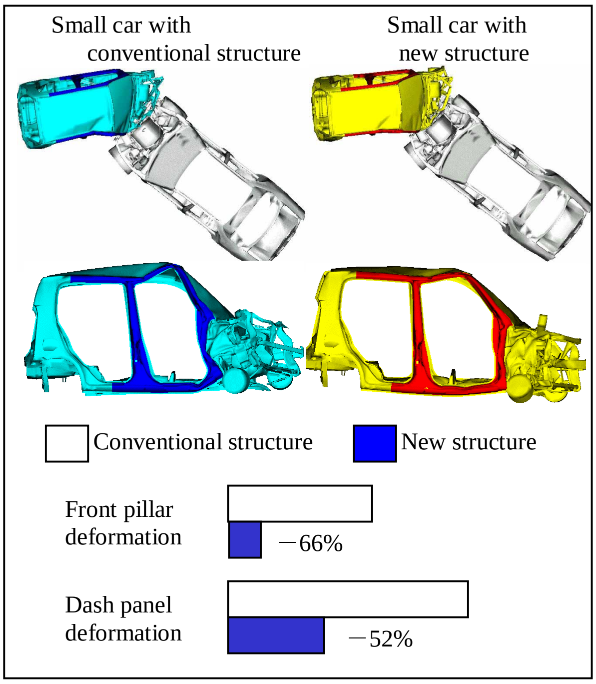


Figure 9. Reducing passenger compartment intrusion for angle of approach in vehicle-to-vehicle collision.

AGGRESSIVENESS

Secondly we give consideration to aggressiveness. As a result of above-mentioned vehicle-to-vehicle simulations, energy absorption in the engine compartment has increased slightly and the energy absorption in the cabin is decreased in large cars with conventional body structures by means of the effect from the new structure. It can therefore be predicted that the new body structure will not increase aggressiveness towards the partner vehicle in a collision (as shown in Figure 10).

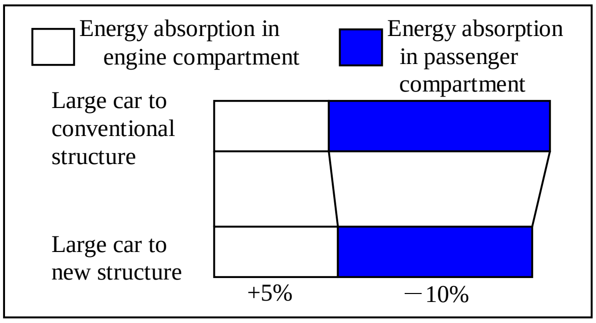


Figure 10. Improving of energy absorption.

Further we analyzed aggressiveness towards small cars as follows. We describe the simulation results in a frontal collision between similar small cars A and B with conventional structure (case 1), and between a small car A with conventional structure and a small car C with the new proposed structure (case 2)in Figure 11. Opposite car's intrusion in the passenger compartment was approximately similar in both cases. We could assess that our proposed new structure greatly improved self-protection, and doesn't increase the aggressiveness towards the small car, and we could find the possibility for compatibility.

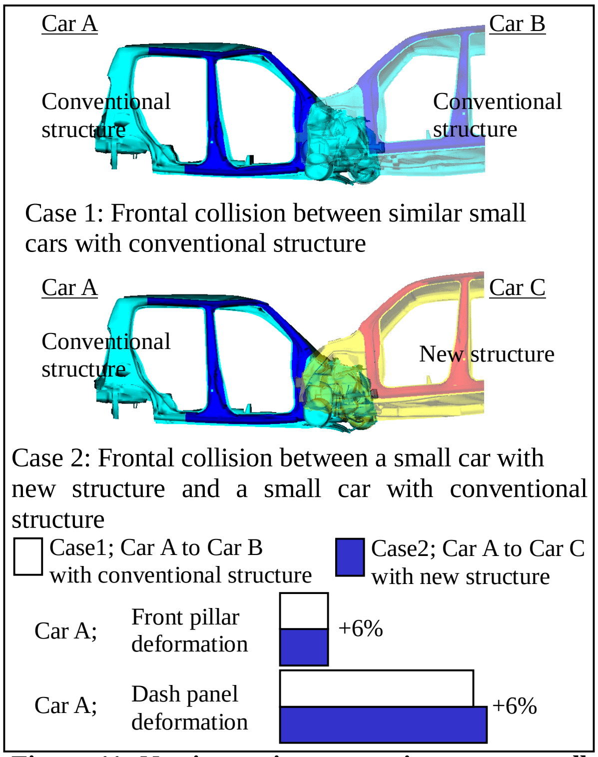


Figure 11. Not increasing aggressiveness to small cars.

ACCIDENT ANALYSIS

This time the condition in a vehicle-to-vehicle crash test was based on the accident analysis in Japan. Some accident data were provided from the Institute for Traffic Accident Research and Data Analysis (ITARDA) established in 1992.

Almost half of the number of occupant deaths is in the case of frontal collisions as shown in Figure 12[1]. About 90% of the frontal collision deaths were at speeds lower than 50kph as shown in Figure 13 [1]. And when the opposite vehicles are heavier than the subject vehicles, the driver deaths in frontal collisions are about 75% as shown in Figure 14 [1]. With relation to overlap in frontal collisions, 30% and 50% overlap cases are the primary overlap conditions for offset collisions (as shown in Figure 15) [1].

For reduction casualties, we would get effective test results from test condition based on accidents analysis.

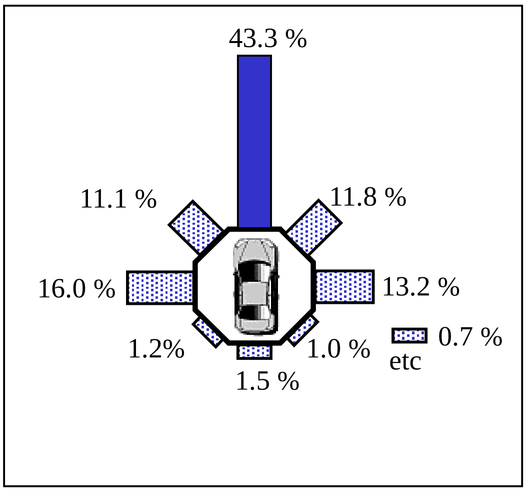


Figure 12. The collision direction in the fatal accidents for vehicle-to-vehicle collisions.

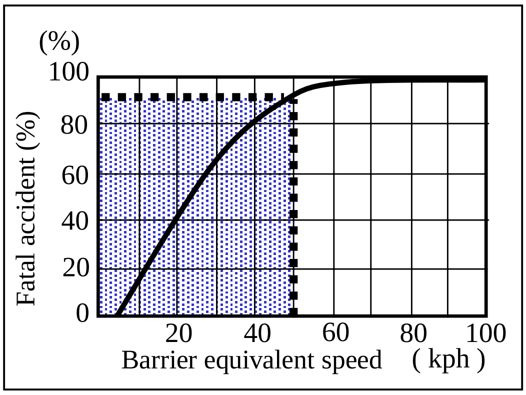


Figure 13. Fatal accident speed and percentage in frontal collisions.

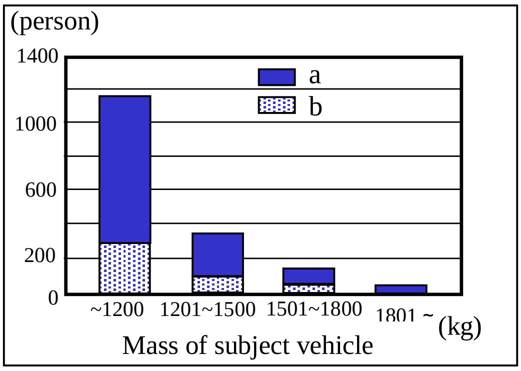


Figure 14. Vehicle mass and the driver fatalities of subject vehicle in frontal collisions.
; a) The opposite vehicle is heavier than the subject vehicle.
; b) The opposite vehicle is lighter than the subject vehicle.

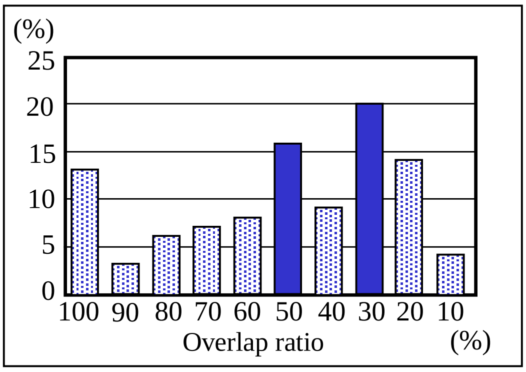


Figure 15. Overlap ratio in frontal collisions.

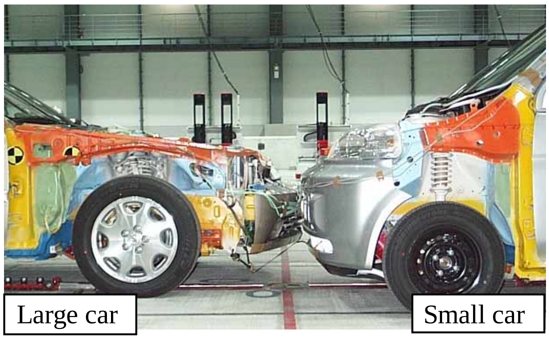
TEST CONDITIONS

The target in this test is the verification for a small car’s self-protection in the conditions based on real world accidents, especially the improvement of geometrical interaction in the frontal structure.

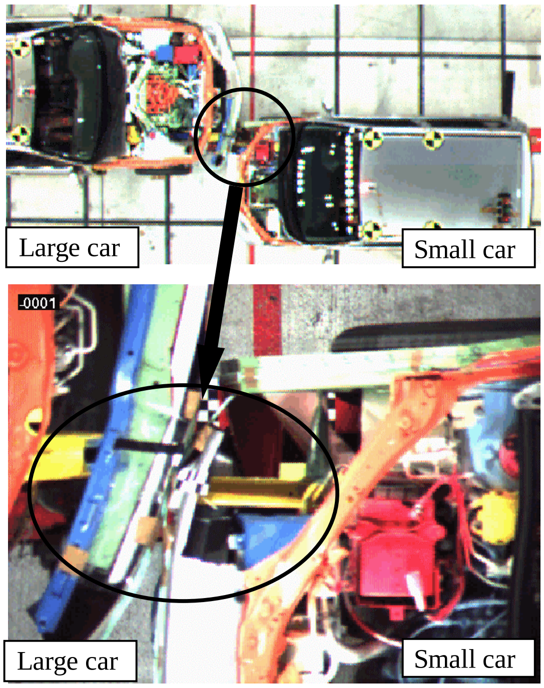
Small car: Prototype model
(This time only the ‘Lower member system’ was added on.)
Large car: Conventional model
Speed: 50kph per car
Mass : Small car 985kg Large car 1855kg
Mass ratio: 1.9 (Large car／Small car)
Overlap ratio: 50% of small car

The 50% overlap case is the reason that the risk of injury is higher than 30%. (as shown in figure 7)
Impact angle is 0°to the car’s longitudinal axis.
Figure 16 shows the two cars before the crash test.
The main structural layouts of the cars are shown in Figures 17.

Figure 16. Two cars before the crash test.



Bumper heights are approximately the same.



The main frame of the vehicles did not overlap in the direction of width.

Figure 17. Main structural layout of two cars.

In this test the main frames of the cars did not overlap in the direction of the cars' width, and the bumper heights were approximately the same.

Dummy: HybridⅢ

Restraint system: airbag and seat belt pretensioner with load limiter.

The restraint specification is similar to a small car without suitable modification for the change of the vehicle's deceleration characteristic.

TEST RESULTS

Speed: Small car 50.0kph
Large car 49.9kph
Overlap ratio: 48% of Small car
Figure 18 shows two cars after the crash test.
The structural deformation of the small car and the large car is shown in Figures 19 and 20 respectively.

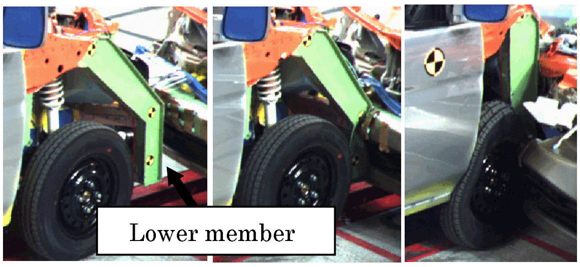
The mode of structural deformation in the engine compartment of the small car during the crash is shown in Figure 21. Figure 22 shows deformation in the engine compartment of the small car after the crash.

Each part of deformation in both cars is listed in Table 1. Figure 23 shows the velocity change of both cars.

Figure 18. Two cars after the crash.

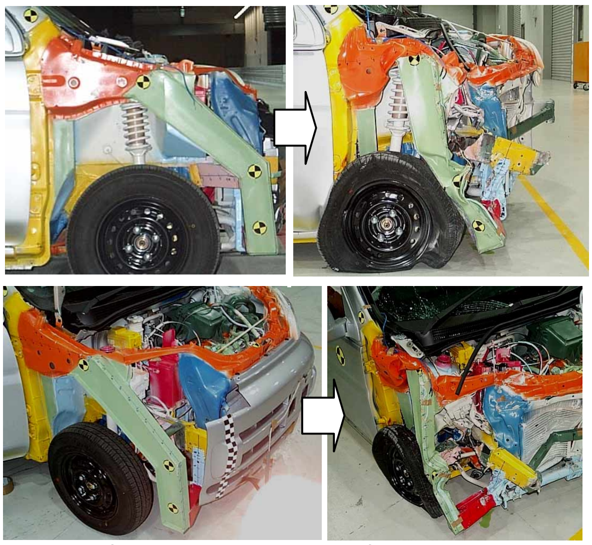
Figure 19. Deformation of small car with the new structure after the crash.

Figure 20. Deformation of large car after the crash.



0msec 10msec 38msec

Figure 21. Deformation mode of small car's new structure during the crash.



Before the crash After the crash

Figure 22. Deformation of small car in the engine compartment after the crash.

Table 1. Deformation

		Small car with new structure	Large car
Deformation	Front pillar(mm)	13	9
	Dash panel(mm)	114	162

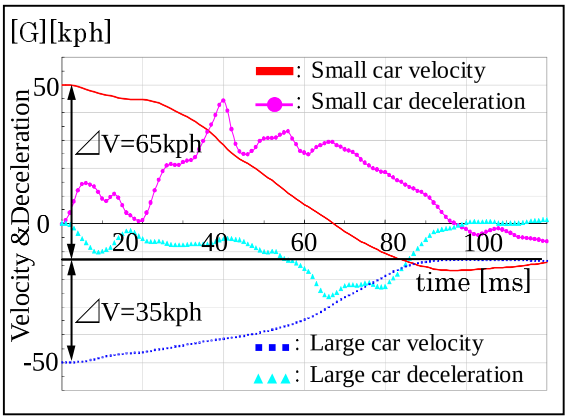


Figure 23. Velocity & Deceleration of both cars.

The vehicle-to-vehicle crash test confirmed the effectiveness of the new design in increasing the level of self-protection of small cars. The mode of deformation on impact confirmed that the bumper beam and main frame of the large car collided with the new lower member fitted in the small car.

The lower member restrained intrusion into the small car by making contact with the tire and wheel. Intrusion of the passenger compartment was therefore significantly reduced and the integrity of the cabin was maintained for occupants. The large car deformations in each part were approximately similar with the small car deformations.

The risk of injury to the small car's occupants were generally low by the prevention of secondary collisions in the passenger compartment.

The test results show the small car driver's injury risk is higher than the large car driver's injury risk. The reason is that the small car's Δ V[65kph], (namely the velocity change of before and after impact) is higher than the large car's Δ V[35kph], due to the influence by mass ratio.

CONCLUSION

A small car to large car crash test confirmed that the new body structure is one of the ways in increasing the level of self-protection of small cars.

It is very difficult for small vehicles with conventional body designs to maintain cabin integrity in narrow offset collisions and collisions with SUV because of the intrusion of the frame of the other vehicle

The innovative body structure proposed in this research reduces passenger compartment intrusion and occupant injury by restraining frame intrusion and enabling a high level of energy absorption in the engine compartment.

The structure improves the level of self-protection in small cars, it is also expected to improve the level of partner-protection offered by large car. As a further step we are going to research the aggressiveness for large cars based on the proposed new structure in this report.

Therefore, new design concept in making vehicles isn't an individualistic one and doesn't aim for only superior self-protection. Rather, the concept is harmony with the society of automobiles.

Finally it is hoped that the proposal of this new structure will trigger further research on body structures enabling reduction of traffic accident casualties in the future.

REFERENCES

[1] The Annual Reports of Traffic Accident Research and Data Analysis.1996.ITARDA.